Employing the Flash Flood Potential Index (FFPI) with Physical Environmental Factors in Baling, Kedah through GIS Analysis

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Abstract
On July 4, 2022, Sungai Kupang, Baling, Kedah experienced a devastating flood that caused 3 fatalities, destroyed or damaged 17 houses, affected 3,546 residents, and resulted in losses estimated at RM25.91 million. The flood was triggered by heavy rainfall in the highland area, which caused multiple landslides to occur simultaneously. The landslides led to a debris flow phenomenon in four main river branches, ultimately resulting in a tragic debris and mud flood in the lowlands and downstream villages. The aim of this study is to analyze the location of flash flood occurrences in Baling and to estimate the likelihood of flash floods based on the identified land physical factors. This study also identifies the critical area of Baling basin that have high potential for a flash flood and evaluates the effectiveness and applicability of the FFPI model compared with historical flood events and remote sensing imagery which have occurred in the few watersheds area. The FFPI model, which was created for the first time in 2003, is used in this study to analyze the flash flood that occurred in Baling by considering slope, land cover, soil data, and vegetation. The FFPI technique is applied in five scenarios to determine the flash flood potential, and the value used is also based on the references. A value of 1 on the index denotes a minimal probability of flash floods, while a value of 10 indicates the highest probability. Based on the findings, the study area had a high possibility of having a flash flood at an index value of 7. The danger level of a severe flash flood is present throughout the research region in all scenarios when the value is more than 50%. The outcome is then utilized to do comparisons using historical information on flash floods and their hotspots area, as well as utilizing satellite imagery to determine the true scale of the flood. This is also important to reduce the impact of floods occurrence in the same place as well managing risk and to plan for disaster-mitigation operations.

Keywords: Baling, FFPI, Flood, Flash Flood Potential Index, GIS, Kedah

1. Introduction

Climate change refers to the long-term alteration of a location's temperature, resulting in unpredictable changes in weather patterns. This phenomenon is responsible for the increasing frequency and intensity of typhoons, floods, rainstorms, and winter storms [1]. The burning of fossil fuels such as coal, oil, and gas has contributed to climate change by heating, moistening, and energizing the Earth's atmosphere. The impact of climate change extends beyond nature and affects human society, particularly in economic, health, and social aspects. The planet's water cycle is also affected by climate change, with wet areas becoming wetter and dry areas becoming drier. Intense downpours are becoming more common, leading to an increased risk of flooding. Extreme rainfall is also on the rise, further contributing to flooding. This is because warmer air is capable of holding more moisture, leading to more intense storms. According to Doswell III [2], flooding is a weather-related calamity that affects people worldwide. Floods occur when water spills over onto dry land, typically due to heavy rainfall. However, flooding can also be caused by factors other than the weather. As a result, a comprehensive understanding of floods must consider the underlying mechanisms connecting meteorological phenomena to floods. Regardless of the event that triggers a flood, the root cause of flooding is the atmospheric processes that produce precipitation, which may have occurred a long time ago.

2. Materials and Methods

This section outlines the scope of the study, as well as the data collection methods and GIS analytical techniques used. The study employed FFPI methods to assess the probability of flash floods in a particular location based on its land physical characteristics.

2.1 Study Area and Data Collection

Baling District is a major town in the northern state of Kedah with an area of 1,529 km^2. The river basin is situated in the north-west part in Peninsular Malaysia and the catchment area is around 4210 m^3. The study area has atmosphere shifting from the rain-storm season where it covers the aggregate region of 11,252 km^2 and the zones incorporate three states which are Kedah, Perlis, and Penang. The place was chosen due to frequent flash floods occur by continuous rainfall coupled with forestry activity. Due to the proximity of the catchment areas to Sg Kupang and Sg Ketil, there is a higher probability of flooding in the area. The data collected are mostly from proprietary data and open-source data. The data are in vector and raster format. Table 1 shows the data collected for the classification of flash flood potential, while Table 2 shows the data collected for the verification of flash flood from https://search.asf.alaska.edu/.

2.2 Data Preparation for FFPI

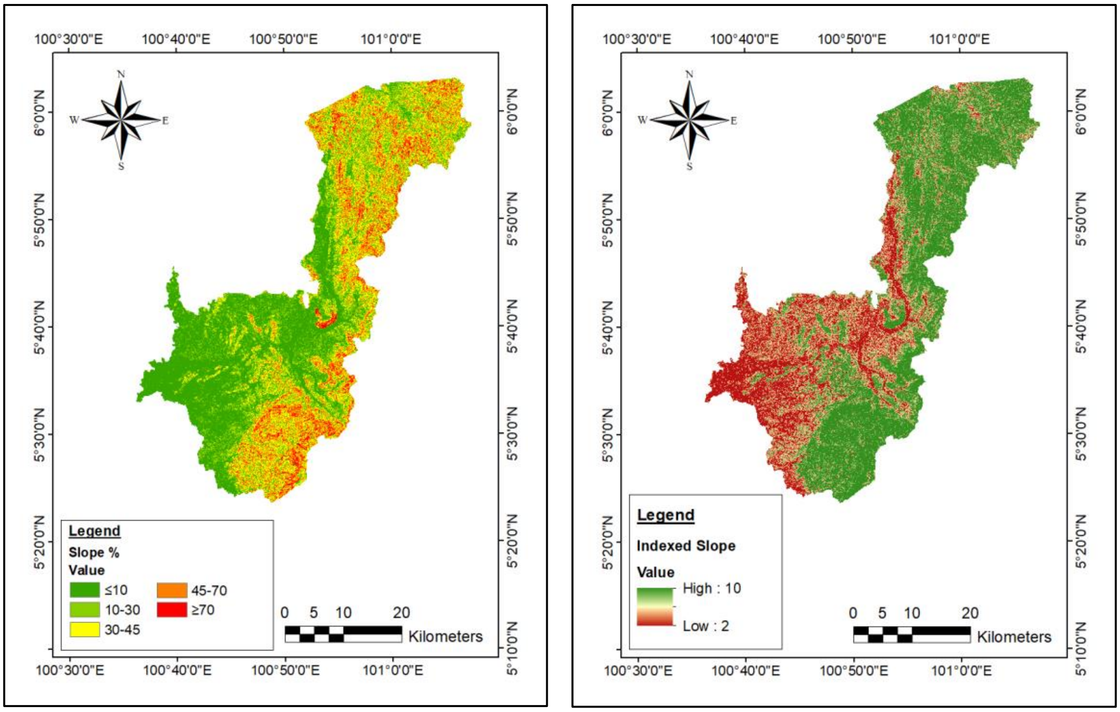
The FFPI methodology utilized four primary types of data or parameters, including slope, soil, land use/land cover (LULC), and vegetation index of NDVI. These parameters were prepared and classified according to the FFPI requirements as shown in Table 3 below. Slope plays a crucial role in runoff, and Figure 1(a) illustrates the percent slope of the study area, while Figure 1(b) shows the FFPI-reclassified slope. The types of soils in the study area are displayed in Figure 2(a), where Acrisols are low base saturation acidic soils, Histosols are soils with a high amount of organic matter, Andosols were formed from volcanic parent material, and Cambisols are formed from alluvial, colluvial, and aeolian deposits. The majority of Ferralsols have good physical characteristics, and they are less likely to erode than most other heavily worn red tropical soils. Figure 3(a) shows the LULC types for the study area, which are mostly mount forest and forestland. Figure 3(b) displays the LULC reclassification used in FFPI. NDVI uses red and near-infrared wavelengths to enhance vegetation features and canopy structure, and Figure 4(a) shows the vegetation index of the study area. Figure 4(b) displays the reclassified NDVI factor.

Table 1: Data collected and used for FFPI

Datasets	**DEM**	**Soil Type**	**Landcover**	**Vegetation**
Sources	Shuttle Radar Topography Mission (SRTM) [2017]	Digital Soil Map of the World (DSMW) [2022]	Land Use/Land Cover (LULC) [2022]	Landsat-8 [1/2/2022]
Provider Data source	United States Geological Survey (USGS) https://earthexplorer.usgs.gov/download/options/srtm_v3/SRTM1N05E101V3	ISRIC World Soil https://soilgrids.org	PLAN Malaysia	United States Geological Survey (USGS) https://earthexplorer.usgs.gov/download/options/landsat_ot_c2_12/LC08_L2SP_128056_20220201_20220505_02_T1

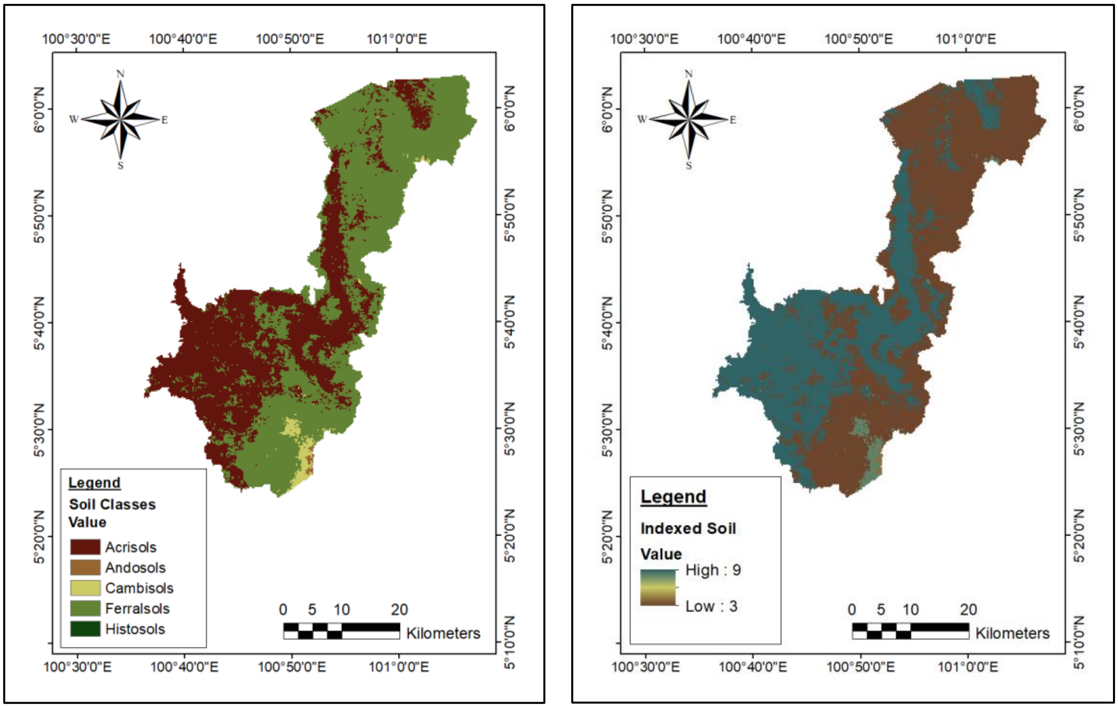
Table 2: Sentinel-1 data collected for flash flood verification

Satellite	**Mode**	**Polarization**	**Direction**	**Date**
Sentinel-1 GRD	Interferometric Wide (IW)	VV+VH	Descending	08/03/2022
Sentinel-1 GRD	Interferometric Wide (IW)	VV+VH	Descending	24/06/2022



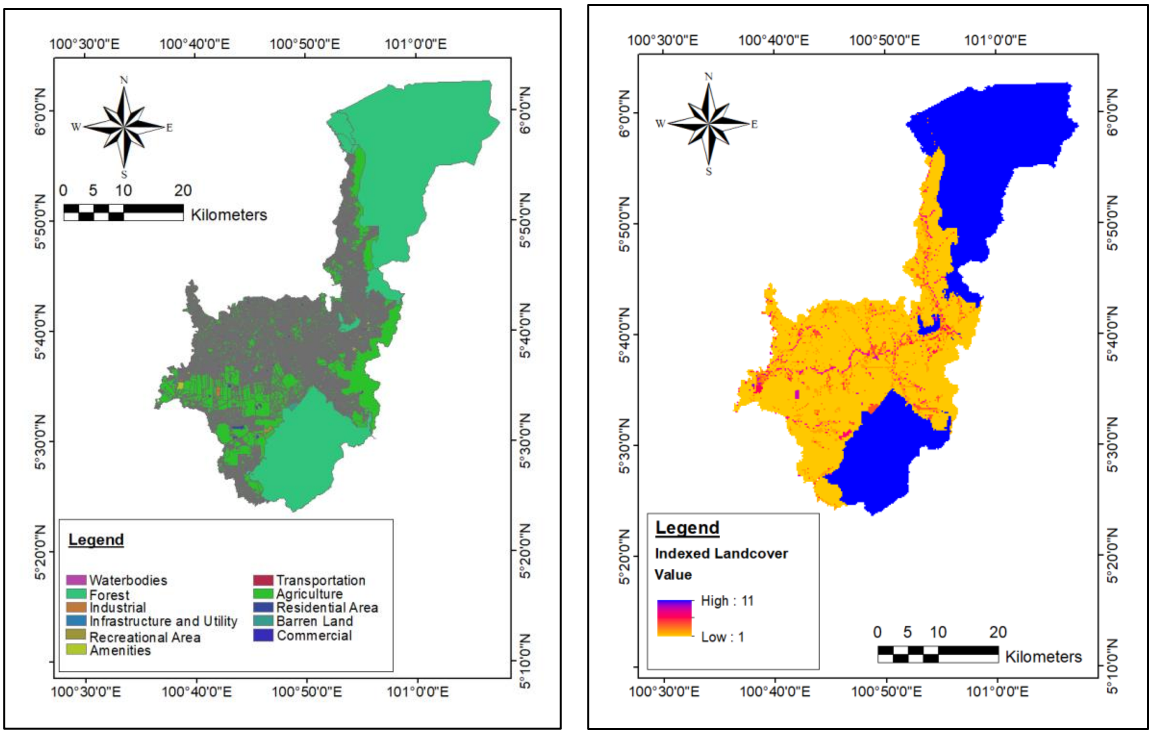
(a) (b)

Figure 1: Slope factor of FFPI: (a) Slope map, (b) Reclassified slope map



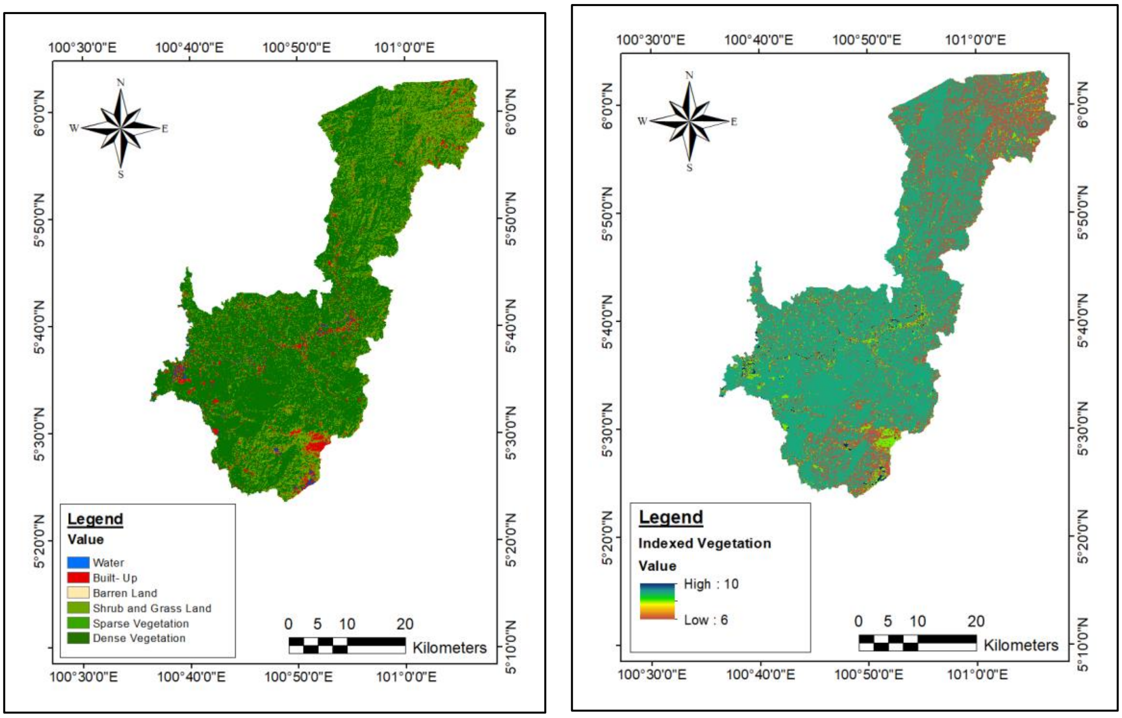
(a) (b)

Figure 2: Soil factor of FFPI: (a) Soil map, (b) Reclassified soil map



(a) (b)

Figure 3: Landcover factor of FFPI: (a) Landcover map, (b) Reclassified landcover map



(a) (b)

Figure 4: Vegetation of FFPI: (a) Vegetation map, (b) Reclassified vegetation map

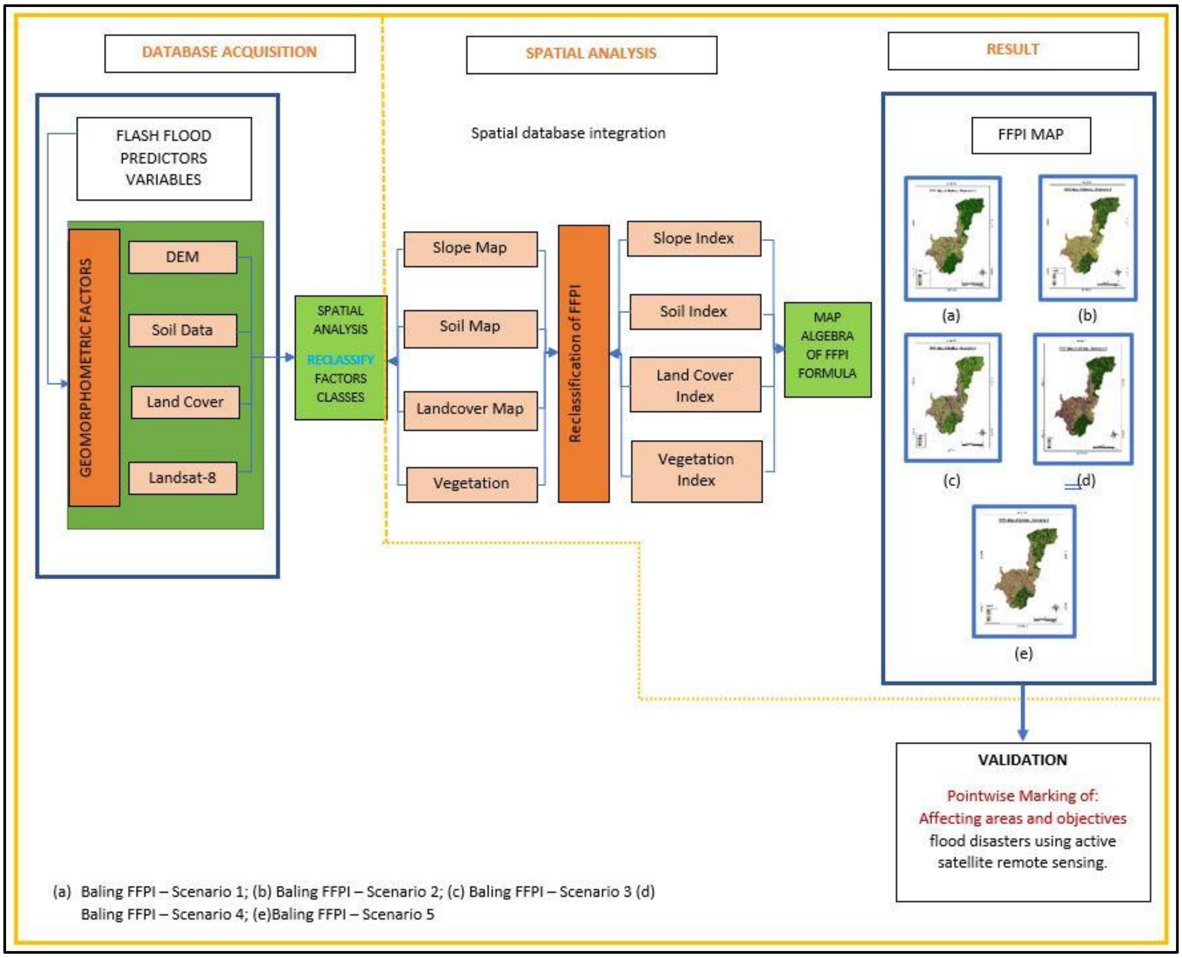


Figure 5: Methodology flowchart of using FFPI

Table 3: The FFPI values were allocated to each dataset based on their level of vulnerability to flash flooding [3] [4] [5] [6] [8] [9] [10] and [11]

FFPI Value	Slope/DEM (%)	Land use	Vegetation cover (%)	Soil type
1	< 3	Water	90-100	Water/Alluvial
2	6	Woody Wetlands, Herbaceous Wetland	80-89	Sand
3	9	Evergreen Forest	70-79	Sandy Loam
4	12	Mixed Forest	60-69	Silty Loam, Loamy Sand
5	15	Deciduous Forest	50-59	Silt/Organic matter
6	18	Pasture Hay, Cultivated	40-49	Loam
7	21	Developed/open space, Barren Land	30-39	Sandy Clay Loam,
8	24	Developed/low	20-29	Clay Loam, Sandy, Clay
9	27	Developed/medium	10-19	Clay
10	30 and above	Developed/heavy	0-9	Bed, Rock/Impervious

2.3 Derivation of Flash Flood Potential Index (FFPI)

The FFPI, which stands for Flash Flood Potential Index, was developed in 2003 by the Colorado Basin River Forecast Centre of the National Weather Service. The method considers several factors including slope, vegetation cover/density, soil texture, and land use to create a numerical index that indicates a region's potential for flash flooding [3]. These factors are collected as raster datasets and processed using GIS methods to form the FFPI. The FFPI's data processing phases are shown in Figure 5. The FFPI objective is to statistically characterize the risk of flash flooding for a given area based on its inherent, static properties, such as slope, land cover, land use, and soil type/texture. The FFPI gives users the ability to discover which subbasins are more likely than others to experience flash flooding by indexing the risk of flash flooding for a certain location. As a result, the FFPI can be included among the situational awareness techniques that can be used to evaluate the danger of flash floods [10]. The hydrologic response properties of each data layer were rated between 1 and 10, with a value of 1 indicating the lowest potential for flash floods and 10 indicating the highest potential. The FFPI assigns a value between 1 and 10 to each of these variables based on their susceptibility to flash flooding. In the updated FFPI slope was given more significant weight than vegetation cover, meaning that places with the steepest slopes have a higher possibility of experiencing flash floods. Indicating a higher likelihood of flash floods in areas with steep slopes [6]. Each component now receives the same amount of weight, with additional weighting given to slope and land cover/use. Many researchers have used the FFPI method, as shown in Table 3. The main change was that each component received the same weight [4], and additional weight was given to slope and land cover/use [7].

To generate the FFPI map, the Spatial Analyst tool in ArcGIS is employed using raster map algebra or raster calculator. The FFPI technique is applied to assess the likelihood of flash floods in five different scenarios, as presented in Table 4. Once the FFPI calculation is complete, the outcomes are reclassified in the second phase to determine the amount of risk posed by the potential for flash flooding.

2.4 Result Verification Using Historical Data

Once the FFPI classification is completed, the validation process is carried out by utilizing historical data obtained from remote sensing imagery that corresponds to flash flood incidents. The SNAP software provided by Sentinel is used to process satellite images. The FFPI classification is also verified using an alternative method, which involves utilizing Kernel Density to identify hotspot areas based on the available historical flood data. The Kedah Department of Irrigation and Drainage provided the historical data for floods in Baling, which is in vector format and presented as points.

3. Results and Discussion

3.1 FFPI of Baling in Five Scenarios and Percentage Area of FFPI Value

The findings derived from the FFPI equations have been illustrated in Figures 6(a) to 6(d) under the corresponding Scenario 1 through Scenario 5, as delineated by the FFPI scenarios specified in Table 4. The FFPI values are demonstrated in Table 3 and are measured on a scale of 1 to 10. These values are represented through a color-coded scheme, where the color green indicates a high potential and the color purple indicates a low potential. The findings reveal that augmentation of the slope's weight along with variations in land used in distinct FFPI equations leads to an elevation in the FFPI's numerical value. The reduction of vegetation density by 50% yielded limited impacts on the significance of the FFPI.

Based on the results of the various scenarios analyzed, it can be concluded that a significant proportion of the FFPI values within the studied region are found to be within the range of 5 to 7. One of the factors that significantly contribute to the overall value of the FFPI is the prevalence of natural forests, hilly terrain, and mountainous areas adjacent to riverways within the study region. The urban locality of Baling, which is the primary subject matter of investigation, is a populated settlement situated adjacent to a river and situated at the foothills of a mountain. It can be suggested that the location of the study area was a contributing factor to the occurrence of the flash flood. Within each of these specified conditions, the geographic location nearest to a waterway and situated at the foot of a mountain is most susceptible to flash flooding. If the numerical value exceeds 50%, there is a significant probability of a severe flash flood event taking place within the investigated region. The elevated prevalence of high-risk situations in the study area can be primarily attributed to its proximity to the main river and its positioning at the foot of a steep mountain. The presence of a considerable danger level and its prevalence as a component of all likely consequences is discernible within the research domain.

In this research, the slope and land use weights in the employed equations were found to be the study's most important variables.

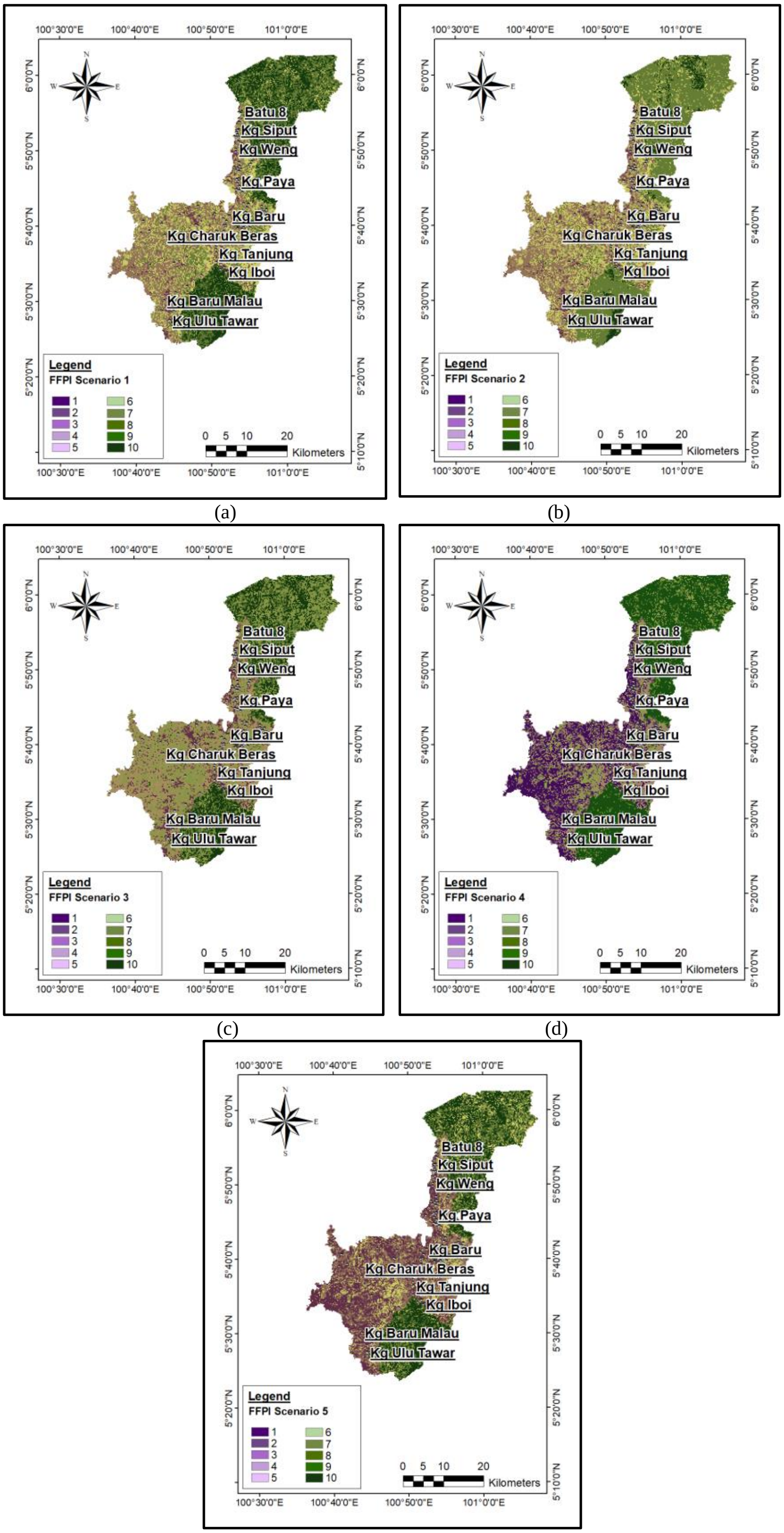


Figure 6: FFPI of Baling: (a) Scenario 1, (b) Scenario 2, (c) Scenario 3, (d) Scenario 4, (e) Scenario 5

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Table 4: Equations used for FFPI scenarios [11]

Scenario	Equation used	Source
1	$\frac{(1.5M + L + S + V)}{4.5}$	[3]
2	$\frac{(1.5(M) + L + S + 0.5(V))}{4}$	[6]
3	$\frac{(M + L + S + V)}{4}$	[4]
4	$\frac{(2(M) + 2(L) + S + V)}{6}$	[7]
5	$\frac{(1.5(M) + 1.32(L) + 1.16(S + 1.02(V))}{5}$	[11]

Table 5: Percentage of area in FFPI scenarios

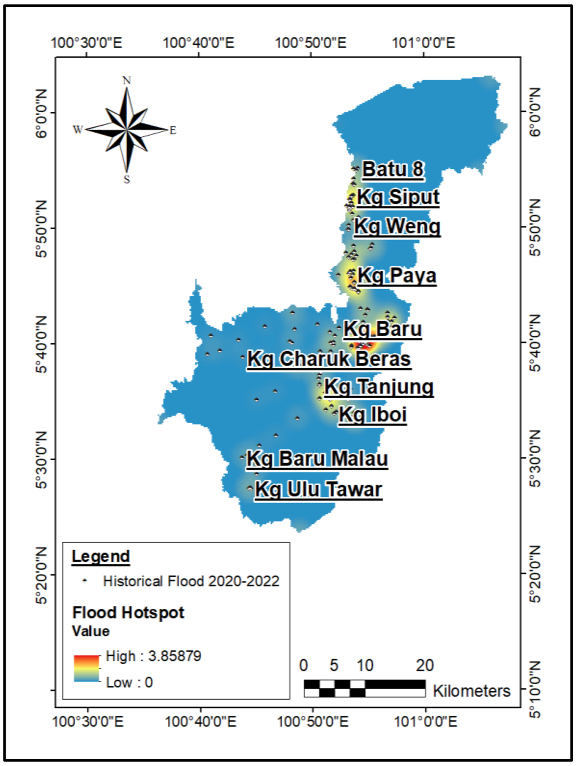
FFPI	Percentage of area belong to different FFPI values (%)				
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
1	0%	0%	0%	0%	0%
2	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%
4	6%	0%	4%	4%	4%
5	23%	23%	24%	22%	0%
6	23%	19%	0%	0%	38%
7	28%	0%	41%	38%	16%
8	0%	37%	0%	0%	21%
9	20%	21%	31%	0%	0%
10	0%	0%	0%	36%	21%

The present investigation underscores that scenario 4, which relied upon the expertise of Ceru [7], demonstrated a more efficacious approach to flash flood mapping in the examined geographical location. Approximately 58.4% of the targeted research area exhibited an FFPI ranging from 5 to 7. When the risk level for each scenario was evaluated, it was apparent that most of the study area was at a medium risk level. In general, Baling has a 39% chance of experiencing an extreme level flash flood, a 16% chance of a high-level flash flood, and a 46% chance of a medium-level flash flood.

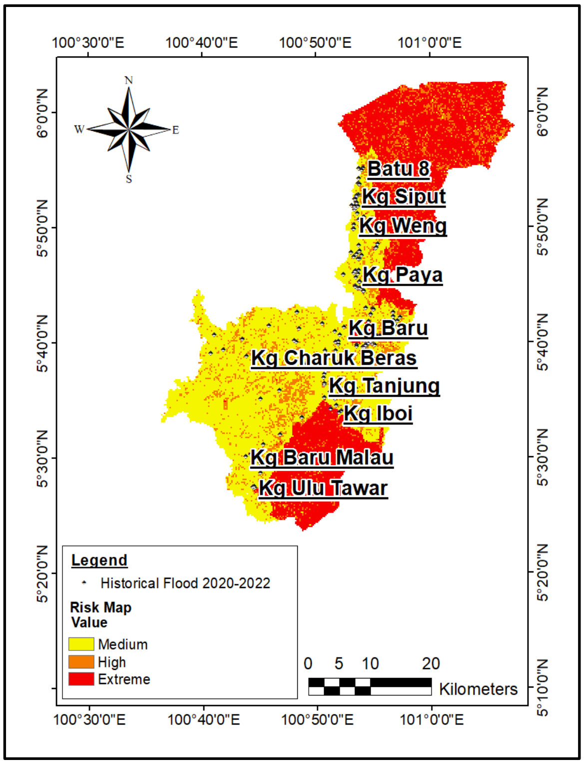
Table 5 presents the percentage of the study area covered by the FFPI values for each scenario. The results show that the potential for flash floods in the study area falls within the mid-range of the FFPI values across all scenarios. Scenario 4, however, has the highest potential index values, ranging from 5 to 7. When the FFPI is set to 10, both scenarios cover over 40% of the study area. These findings suggest that the whole study area is at a moderate risk of flash flooding. Some of the areas at moderate risk include Kg Pokok Sena, Kg Pantai Pulai, and Kg Telok Pedati, which are located near Sg Kupang and Sg Ketil, and are overlay on a base map.

3.2 Comparison of Historical Data of Flash Flood Occurrence with FFPI

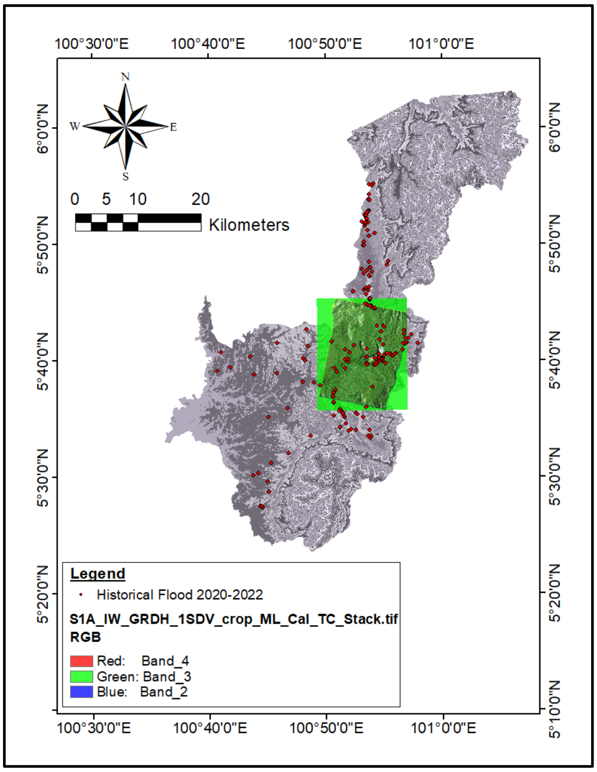
The data from previous years is analysed to identify the areas where flash floods have occurred frequently, also known as the hotspot areas. Figure 7(a) presents the hotspot region of flash flood in Baling. The blue colour denotes an area that always experiences floods, while the orange colour represents an area that experiences the disaster on a more frequent basis. The region has a low risk of being affected by flash floods, as indicated by the light blue colour. In Figure 7(b), the results of reclassifying the FFPI into three risk categories, namely medium, high, and extreme, are shown. This is overlaid with historical data on flash floods. When compared to Figure 7(a), the location of the hotspot area of the occurrence can be found inside the region that is at a high risk of being affected by flash flooding. However, as same as the previous section comparison, the area that falls under the level of extreme risk that could happen flash flood according to its potentiality, is not the hotspot area of flash flood occurrence where it falls under the area that is seldom occurred floods from past data.



(a)



(b)



(c)

Figure 7: Comparison of outcomes: (a) Historical data hotspot area, (b) Baling Historical flood, (c) Flood extent from Sentinel-1 GRD

On the other hand, Figure 7(c) shows the flood map area results from the Sentinel-1 GRD data SAR image. The flood took place in the green area that is depicted with satellite image overlaid, and when compared to the area that is depicted within the historical flood point in Figure 7(b), it can be determined that the flood took place in the area that has a high risk of flash flooding in accordance with its potential. According to the radar image that was obtained, the region that was possibly extremely vulnerable to flash flooding appears to have been affected by the abovementioned tragedy. This finding is consistent with the findings of the prior comparisons, and it appears that the flood disaster impacted the surrounding Baling's Mountain area, which was particularly vulnerable to flash flooding.

3.3 Discussion on Method used for Study Area

Based on the results obtained, the flash flood occurred in the area that was identified to have a high potential for flash flooding by the FFPI, as explained earlier. This finding is consistent with the results of previous comparisons. To further improve the FFPI, a more comprehensive and enhanced version called FFPI Weight-Of-Evidence ($FFPI_{WofE}$) was developed in 2022 [12]. To calculate the WofE percentage value, input response variables and additional factors are required to enhance the FFPI. The Torrential Phenomena Inventory variable is also necessary in the calculation of the WofE value. By conducting a statistically based integrated study of a total of 15 elements, which best highlights the territorial development of the examined process, it will provide a territorial distinctiveness from the perspective of the FFPI. However, since the Torrential Inventory variable was not available, the percentage value could not be calculated.

During the validation process, the identification of locations affected by previous flash floods in areas corresponding to high and very high vulnerability classes in terms of FFPI highlights the effectiveness of the proposed model. This serves as a validation of the methodological approach and supports the recommendation that the results obtained should be utilized and applied in practice.

4. Conclusion

The Flash Flood Potential Index (FFPI) is a method that helps scholars and decision-makers identify areas that are at risk of flash floods. This study employs five different scenarios based on global reviews conducted in the past. The Jordanian expert who assessed the study area's characteristics (including slope, land use/cover, soil texture/type, and vegetation cover/density) changed the final scenario [11]. The weight of slope and land use were found to be the most significant variables in the equations used in this study. With the severity and frequency of slope flash floods increasing, it is becoming more important to conduct hazard and vulnerability studies that are closely linked. Past studies of areas that have experienced extreme events were often carried out locally by agencies in charge of the integrated management of catchment areas after the fact and did not consider how such events could have been estimated to reduce the potential for harm. The study in Baling explores diverse research areas through the utilization of five distinct equations, giving the FFPI value of 7 the most for scenario 4. The findings demonstrate that the parameters of slope and land use weight, as applied in scenario 4, were the most significant factors in this particular investigation. Through comprehensive analysis, all risks associated with various scenarios have been successfully identified. The outcomes of this study reveal that medium-scale risks prevail within the study area.

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References

[1] National Geographic, (2022). *Resource Library, Encyclopedia from Entry*. Retrieved from Climate Change: https://education.nationalgeographic.org/resource/climate-change

[2] Doswell, III, C., (2015). Hydrology, Floods and Droughts Flooding. *Encyclopedia of Atmospheric Sciences*, Vol. 3(2), 201-108. https://doi.org/10.1016/B978-0-12-382225-3.00151-1

[3] Smith, G., (2003). Flash Flood Potential: Determining the Hydrologic Response of FFMP basins to Hydrologic Response of FFMP Basins To Heavy Rain by Analysing Their Physiographic Characteristics. A white paper available from the NWS Colorado Basin River Forecast Centre. Retrieved from 1-11. http://www.cbrfc.noaa.gov/papers/ffp_wpap.pdf.

[4] Kruzdlo, R. and Ceru, J., (2010). *Flash Flood Potential Index for WFO Mount Holly/Philadelphia*. National Oceanic and Atmospheric Administration. Retrieved from https://bgmresearch.eas.cornell.edu/research/ERFFQ/posters/kruzdlo_FlashFloodPotentialIndexforMountHollyHSA.pdf.

[5] Arachige, R. and Perera, D. J., (2015). *Mapping Flash Flood Potential Using GIS and the Flash Flood Potential Index (FFPI) in the Turtle River and Forest Watersheds in North Dakota*. Master Dissertations, Department of Geography and Geographic Information Science, University of North Dakota. https://commons.und.edu/theses/1826/.

[6] Brewster, J., (2009). *Development of the Flash Flood Potential Index*. A Microsoft PowerPoint presentation. Retrieved from: http://www.erh.noaa.gov/bgm/research/ERFFW/presentations/june_02_2010/Brewster_Jim_Development_of_FFPI.ppt. 2009

[7] Ceru, J., (2012). The Flash Flood Potential Index for Pennsylvania. 1-31. Retrieved from: *https://proceedings.esri.com/library/userconf/feduc12/papers/user/joeceru.pdf*

[8] Smith, G. E., (2010). Development of a Flash Flood Potential Index Using Physiographic Datasets within a Geographic Information System. Master Dissertations, Department of Geography, The University of Utah. 1-69. https://collections.lib.utah.edu/dl_files/59/0d/590d31179c399e040a6b171fa2feb1ca7d27f0fc.pdf

[9] Minea, G., (2013). Assessment of the Flash Flood Potential of Bâsca River Catchment (Romania) Based on Physiographic Factors. *Central European Journal of Geosciences,* Vol. 5(3), 344-353. https://doi.org/10.2478/s13533-012-0137-4.

[10] Zogg, J. and Deitsch, K., (2013). The Flash Flood Potential Index at WFO Des Moines, Iowa. Retrieved from: *http://www.crh.noaa.gov/Image/dmx/hydro/FFPI/FFPI_WriteUp.pdf*

[11] Shawaqfah, M., AlMomani, F. and Khatatbeh, A., (2020). Mapping Flash Flood Potential and Risk Level Using GIS Techniques and the Flash Flood Potential Index (FFPI) in Amman Zarqa Basin of Jordan. *Jordanian Journal of Engineering and Chemical Industries,* Vol. 3(3), 81-90. DOI:10.48103/jjeci3102020.

[12] Kocsis, I., Bilașco, Ș., Irimuș, I. A., Dohotar, V., Rusu, R. and Roșca, S., (2022). Flash Flood Vulnerability Mapping Based on FFPI Using GIS Spatial Analysis Case Study: Valea Rea Catchment Area, Romania. *Sensors*, Vol. 22(9), 1–21. https://doi.org/10.3390/s22093573.