Impact of Flood on the Built-up Environment - A Case Study of Baddegama DS Division

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Abstract: *Floods, a recurring phenomenon primarily in low-lying basin areas can be interpreted as beneficial for improving soil structure and cropland products, but they can also be viewed as one of the most catastrophic natural disasters adversely affecting human life and the environment. The main reason for the Baddegama area's flooding is the Ging River flowing through it. The purpose of this research is to prevent the damage caused due to the lack of proper understanding of the flood risk in built-up areas. To identify the riskiness of the built-up area, it should overlay the flood inundation map and built-up area map. To create a flood map, five criteria were selected according to the ideas of well-knowledgeable people who lived in the Baddegama area. In order to Land Use Land cover (LULC), slope, rainfall, soil, and water features were identified as the criteria that were affected by the flood in the area. An Analytical Hierarchy Process was used to scale the criteria, and the weighted overlay method was used to create the flood map. LULC map, as well as a built-up map, were created using a Landsat 8 image and a method of supervised classification. The built-up area map was created after performing the Normalized Difference Built-up Index (NDBI). Most built-up areas in the Baddegama are under moderate flood risk. Further, 14% of built-up areas are at high risk. The riskiness levels of the built-up area as a final output of this study could be used when establishing evacuation centers.*

Keywords: *AHP, Normalized Difference Built-up Index (NDBI), Supervised Classification, Weighted Overlay*

1. Introduction

Sri Lanka is suffering from various natural disasters, including weather hazards like cyclones, monsoonal rain, and subsequent flooding and landslides (Disaster Risk Reduction in Sri Lanka, 2019). Intense meteorological conditions, upper atmospheric instability, or low pressure, despite heavy rainfall, create catastrophic flooding and landslides are the main causes of natural disasters in Sri Lanka (De Silva and Jayathilaka, 2014). Among those natural disasters, flooding is the greatest threat to people who are living in the lowland plains of Sri Lanka (Punchihewa, 2019). Not only in Sri Lanka but also floods are one of the world's most periodic, pervasive, devastating, and common natural disasters (Bapalu and Sinha, 2005*).* Although flooding can occur anywhere on the earth's surface, some areas are more vulnerable to flooding than others. Figure 1 shows the different types of disasters from the year 1990 to the year 2018, and the huge damage that caused the disaster was the flood (Disaster Risk Reduction in Sri Lanka, 2019).

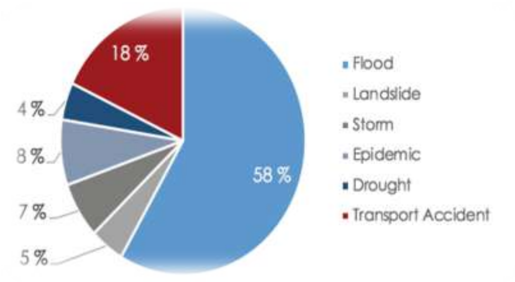


Figure 1. Disaster occurrence from 1990-2018
Source: (Disaster Risk Reduction in Sri Lanka, 2019)

Moreover, flooding is a natural calamity that may cause damage to property, infrastructure, livestock, vegetation, and even living beings (Mustaffa et al., 2016). The wet and intermediate zones get more precipitation than the dry zone, with mean annual rainfalls of 3,000-7,500mm and 2,000-3,000mm, respectively in Sri Lanka (Yoshitani, Takemoto and Merabtene, 2007). Heavy rain and high winds caused by the southwest monsoon on the 25th and 26th of May caused the flood, which affected 879,778 people and, resulted in 219 deaths and 74 misplaced. The tragedy destroyed or damaged approximately 80,000 homes, affecting the livelihoods of over 342,000 people who rely on agriculture, the market, and industry for a living (Ministry of Disaster Management, 2017). As per enumeration data, floods have been the danger that has afflicted the greatest number of households over the previous four decades (De Silva and Jayathilaka, 2014). According to the ministry of disaster management of Sri Lanka, the spread of disaster situations was confined only to 15 districts compared to the 24 districts in the year 2016, increased incidents of floods, landslides, and deaths in 2017 made the situation equally challenging.

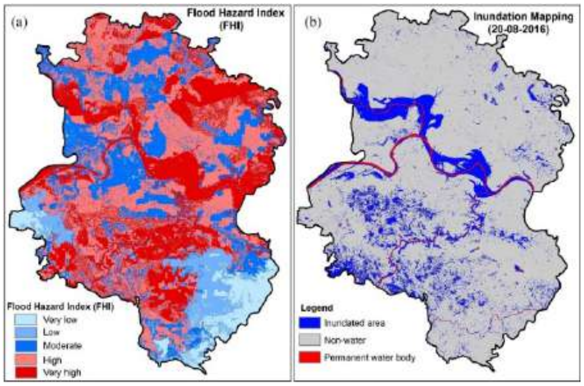


Figure 2. Flood hazard index map and Inundation map
Source: (Dash and Sar, 2020)

Moreover, unauthorized construction, blocking of channel systems, filling of wetland areas, and mining of sand from rivers also cause floods (Punchihewa, 2019). As a result of the flooding, landslides are happening, because of the continuous rainfall, the soil moisture of the area has saturated. It is a disaster for the people who live in the riverside areas. When it rains heavily in the upper reaches of the river, the lower reaches of the river are subject to flooding. Most floods have been observed around major rivers in Sri Lanka. Monsoon floods, on the other hand, take longer to recede and may need evacuating people to flood relief centers for many days (Hasniza Yahya, 2020). People who travel from other districts and become trapped in a flood must have access to real-time flood information, such as road closures or diversions, accessible evacuation stations, and other pertinent information. They need to locate a secure location to stay in while they wait for support.

Remote sensing and Geographic Information Systems (GIS) can give spatial data that can be utilized for flood risk assessment, prediction, and monitoring. Flood simulation is also beneficial for flood control, particularly in helping to solve the problem of flood inundation, which is common in the lower plains (Petchprayoon, 2002). As shown in Figure 2 GIS and Remote Sensing helps to create a map of places where flooding happens regularly, and using the collected images, may enable the charting of evacuation routes. As a result of that, government authorities can make informed judgments based on the maps and locations accessible if a weather prediction is provided.

The significance of this study is that before occurring the floods next time we have an idea about the situation and it is very useful for decision-making for evacuating the victims. The study guarantees that future flood hazards are avoided or controlled and handled in a timely and cost-effective manner. The study is likewise similar to an assessment in that it involves not just suggestions but moreover management of flood hazards.

As a case study, the Baddegama area was selected. There were faced with severe flooding in the years 2003 and 2017. Even if not, each year the Baddegama area faces a flood situation. In the year 2017, homeowners of Baddegama town, and the surrounding regions have been forced to evacuate immediately owing to the Gin River Baddegama Dam's rising pressure as a result of the floods (Yapa, 2017). This research aims to identify the effect of the built-up Area during the flood.

2. Methodology

A. Study Area

Baddegama Divisional Secretariat Division (DSD) territory, with its centroid at 6.1783° N and 80.19° E, is 111 km^2 in area and is located in the Southern Province of Galle District, Sri Lanka. Figure 3 shows the study area of this study. There are 286 rainy days in Baddegama, Sri Lanka, and 1974mm of precipitation is accumulated throughout the year. May is the month with the greatest rain, with rain falling for 28 days and an average of 302mm of precipitation. Gin River is the main contributing factor to the flood in Baddegama Division (Aladdin, 2019).

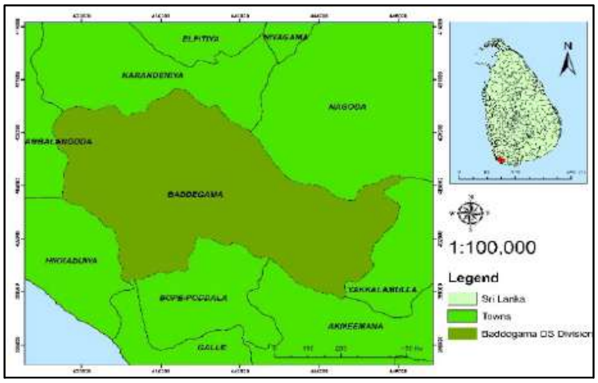


Figure 3. Study Area – Baddegama, Sri Lanka
Source: (Survey Department, Sri Lanka)

B. Data Used

Water features, types of soil, Digital Elevation Model (DEM), and land administrative boundaries data were obtained from the Survey Department of Sri Lanka. DEM was used to create the slope of the area. Monthly rainfall data for the years 2017 to 2021 were used to prepare the rainfall map of the area. That rainfall data were obtained from the Meteorological Department of Sri Lanka. The supervised classification analysis of the Landsat 8 images satisfied the requirement for Land Use Land Cover (LULC). Landsat 8 level 1 satellite image was downloaded from the United States Geological Survey (USGS) Earth explore. (Department of the Interior U.S. Geological Survey, 2016). In the Landsat satellite series, Landsat 8 is the latest series. The main aim of the Landsat 8 satellite is to provide timely, high-quality infrared (IR) and visible images of all landmass and near-coastal areas on the Earth. Table 1 illustrates some Meta data of the Landsat 8 image, which was useful for this analysis. Another critical factor is soil, which has a direct influence on water absorption, permeability, and runoff (Mojaddadi et al., 2017; Shafapour Tehrany et al., 2017). Another important element in assessing flood sensitivity is the distance from the water features, which has been employed in previous research (Elkhrachy, 2015; Shafapour Tehrany et al., 2017).

Table 1. Meta Data of Acquired Landsat 8 Image

Satellite Series	Landsat 8 Level 1
Year	2021
Date Acquired	2021-12-26
Cloud Coverage	4.11%
Cloud Cover Land	6.84%
Weather	Sunny
Map Projection	UTM
UTM Zone	44
Datum	WGS 84
Grid cell size reflective	30.00m

Source: (USGS Landsat 8 Data Users Handbook)

Furthermore, bands 2, and 3,4,5,6 used out of the 11 bands. From them, bands 2, 3, 4, and 5 were used to prepare the Land Use Land Cover Map. And bands 5, 6 were used to perform the Normalized Difference Built-up Index (NDBI). The wavelength and resolution of the above-mentioned bands are illustrated in Table 2.

Table 2. Wavelengths and Resolutions of the Bands

Band No	Band	Wavelength (μm)	Resolution (m)
2	Blue	0.45-0.51	30.00
3	Green	0.53-0.59	30.00
4	Red	0.64-0.67	30.00
5	Near Infrared (NIR)	0.85-0.88	30.00
6	Short Wave Infra-Red (SWIR)	1.57-1.65	30.00

Source: (USGS Landsat 8 Data Users Handbook)

Criteria Finding

In identifying the factors and criteria for flood, the views of well knowledgeable persons living in the Baddegama area were taken into consideration. The Analytical Hierarchy Process (AHP) method was used to assign weights and scales to the criteria and the comments of 36 knowledgeable persons were taken into account.

C. Methodology Applied

Figure 4 illustrates the methodology that was applied for this research. Rainfall is a significant contributor to flood generation (Tehrany, Pradhan and Jebur, 2014). Average monthly rainfall data were used to perform the spatial interpolation of the surface. The monthly average rainfall data were obtained from the five gauge stations around the study area. Three spatial interpolation techniques as Kriging, Spline, and Inverse Distance Weighted (IDW) were used to create the rainfall map relevant to the study area. Finding the Root Mean Square Error (RMSE) is the method to find the best suitable interpolation technique (Das and Wahiduzzaman, 2022). Through the Root Mean Square Error (RMSE), found that IDW is the best suitable interpolation technique for mapping the rainfall data. Following equation 1 describes the way to find RMSE, and Table 3 illustrates the RMSE of three spatial interpolation techniques. Figure 5 shows the final rainfall map.

Figure 4. Methodological Framework

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \hat{X}_i)^2}{N}} \qquad (1)$$

(Das and Wahiduzzaman, 2022)

Where;

X_i = Actual Observation Value

$\hat{X}_i$ = Estimated Value

N = Number of Years

i = Variable

Table 3. RMSE of Gauge Stations

RMSE	Wathurawila Gauge Station	Hiniduma Gauge Station
IDW	14.49260	15.03738
Spline	21.94607	17.25700
Kriging	15.03667	15.97120

Bands 2, 3, 4, 5, and 6 of the Landsat 8 image were subjected to preprocessing. The Land Use Land Cover Map (LULC) was created using Supervised Classification. According to the Land Use Land Cover classification, the Baddegama DS Division was divided into 7 classes, open water area, paddy area, forest area, tea cultivated area, rubber cultivated area, coconut cultivated area, and built-up area. With the help of Field Observations and Google Earth pro software, train the training samples. Furthermore, an accuracy assessment was done to prove the authenticity of the created Land Use Land Cover map. The accuracy assessment of the supervised classification is illustrated in Figure 6. Supervising classification and accuracy assessment are important when preparing a land use land cover map (Rwanga and Ndambuki, 2017). Figure 7 shows the final LULC map. Normalized Difference Built-up Index (NDBI) was performed as shown in equation 2, by utilizing bands 5 (Near Infra-Red) and 6 (Short Wave Infra-Red) of the Landsat 8 image. The accuracy assessment of the Built-up area map is shown in Figure 9. The NDBI values vary from -1 to +1. The positive NDBI values represent urban land areas, whereas negative NDBI values imply non-urban land areas (Zha, Gao and Ni, 2003)

$$\mathrm{NDBI} = (\mathrm{SWIR} - \mathrm{NIR})/(\mathrm{SWIR} + \mathrm{NIR})$$

(2 (Zha, Gao and Ni, 2003)

Land Use Land Cover data, rainfall data, soil data, slope data, and water features data layers were used to create a flood map (as a high-risk area, moderate risk area, and low-risk area) of the Baddegama DS Division. For that, the Analytical Hierarchy Process (AHP) and Weighted Overlay Method were used. AHP is the method to find solutions spatially (Tiryaki and Karaca, 2018).

Then, by overlapping the built-up area and flood map, looked at how much of the built-up area would be subject to different flood levels. Moreover, calculate the area of Land Use Land Cover types according to the different flood levels.

3. Results and Discussion

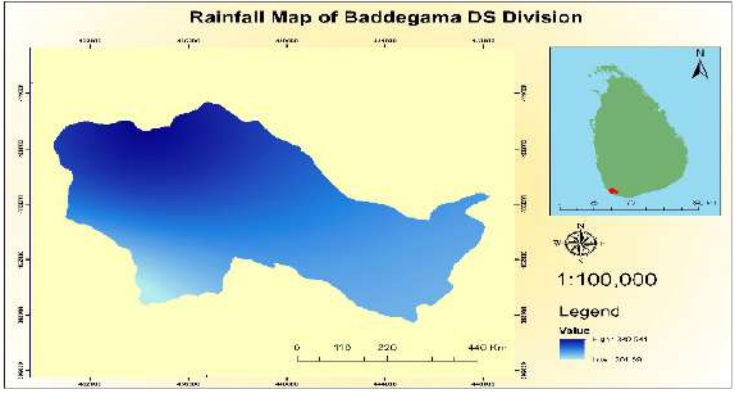
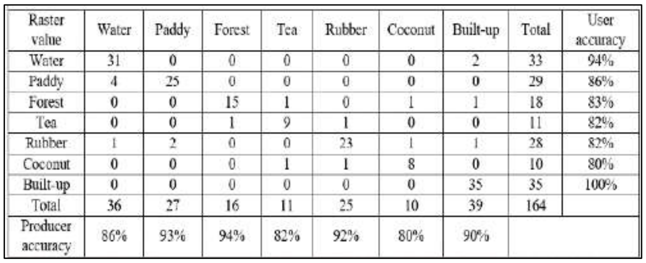


Figure 5. Rainfall Map of Baddegama DS Division



Raster value	Water	Paddy	Forest	Tea	Rubber	Coconut	Built-up	Total	User accuracy
Water	31	0	0	0	0	0	2	33	94%
Paddy	4	25	0	0	0	0	0	29	86%
Forest	0	0	15	1	0	1	1	18	83%
Tea	0	0	1	9	1	0	0	11	82%
Rubber	1	2	0	0	23	1	1	28	82%
Coconut	0	0	0	1	1	8	0	10	80%
Built-up	0	0	0	0	0	0	35	35	100%
Total	36	27	16	11	25	10	39	164	
Producer accuracy	86%	93%	94%	82%	92%	80%	90%		

Figure 6. Accuracy Assessment of Land Use Land Cover Map

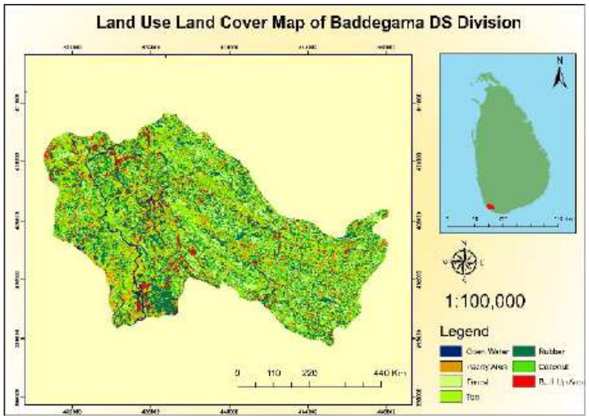


Figure 7. Land Use Land Cover Map of Baddegama DS Division

Table 4. Scales of the Flood Criteria

	Conditions	Scale
Soil	Alluvial soils	4
	Bog and half-bog soils	5
	Red-Yellow podzolic soils	2
	Red-Yellow podzolic soils(flat)	3
Land Use Land Cover (LULC)	Open Water	5
	Paddy Field area	5
	Forest Area	2
	Tea cultivated area	4
	Rubber cultivated area	3
	Coconut cultivated area	2
	Built-Up Area	1
Distance from Water Features	0-100m	5
	100-500m	4
	500-1000m	3
	>1000m	2
Slope	Flat Terrain	5
	Gentle Slope	3

	Steep Slope	1
Rainfall	201-243mm	1
	243-269mm	2
	269-294mm	3
	294-321mm	4
	321-349mm	5

Table 5. Weights of the Flood Criteria

Criteria	Weights (%)
Soil	7
Land Use Land Cover	13
Water Features	19
Slope	27
Rainfall	34

Table 6. Extent of Built-Up Area in Different Flood Risk Condition

	Low-Risk Area	Moderately Risk Area	High-Risk Area
Built-Up Area(Km^2)	5.727	9.669	2.496
Percentage	32%	54%	14%

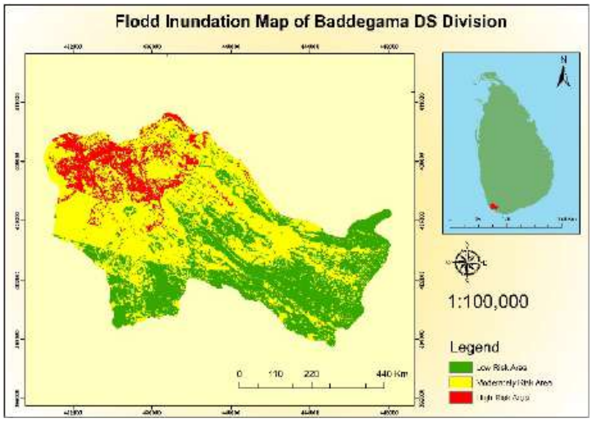


Figure 8. Flood Inundation Map of Baddegama DS

According to the rainfall map prepared by using the IDW interpolation technique, the highest rainfall has been received in the upper catchment areas of Ging River. The maximum rainfall is about 340mm recorded from those areas. It is important to make the LULC map in a manner suitable for the year 2021 by doing a supervised classification. Because even if this is a DS division, some Land Use Land Cover types may change. After studying the LULC map, it appears that most of the land use in the Baddegama area is paddy cultivated. Hence, the groundwater level in these areas is always high. It also directly affects the occurrence of floods in these areas. Also, the crops of tea, coconut, and rubber are spread over the entire area. As shown in the flood inundation map, the high-risk areas are the upper areas of the Ging River. By performing Normalized Difference Built-up Index (NDBI), the built-up area can be extracted very easily and a built-up area map can be prepared for the year 2021. As for the flood risk in built-up areas, about 54% (9.699 Km^2) of built-up areas are moderately

	Built-Up Area	Non Built-Up Area	Total	User Accuracy
Built-Up Area	33	06	39	85%
Non Built-Up Area	07	34	41	83%
Total	40	40	80	
Produce Accuracy	83%	85%		

Figure 9. Accuracy Assessment of Built-Up Area Map

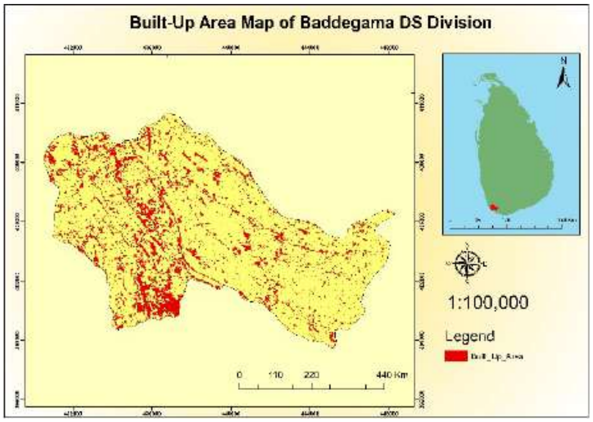


Figure 10. Built-Up Area Map of Baddegama DS Division

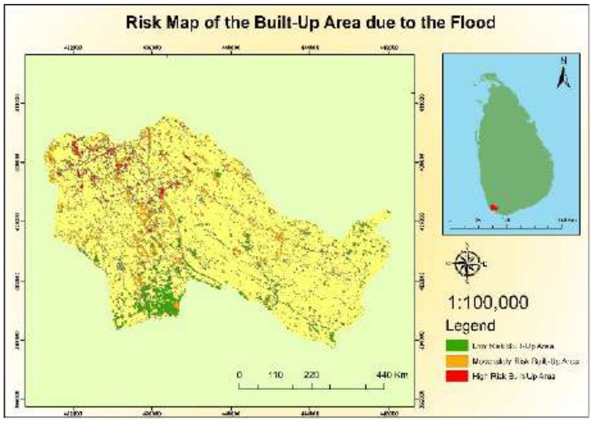


Figure 11. Flood Risk Map of the Built-Up Area

risky flood areas. Moreover, 14% (2.496 Km^2) of built-up areas are in highly risky flood areas. As well as 32% (5.727 Km^2) of built-up areas are in moderately risky flood areas. Although the amount of built-up in high-risk flood areas is low, the amount of built-up in moderately risky areas is high. As a percentage, it is about 40 %.

IV. CONCLUSION AND RECOMMENDATION

It can be said in this study, that to cause the flood in this area, the huge contributing factor is the Ging River, which flows across the Baddegama DS Division. With very high precipitation in Ging river's upper water catchment areas, the built-up areas in those areas are more vulnerable to flooding.

The final risk map of the built-up area can be recommended to find a suitable place to provide shelter to the evacuees in case of sudden flooding. Then the buildings in high-risk areas can be avoided and suitable places to build evacuation centers can be found. The final output could have been accurate if the resolution of the Landsat image was less than 30m. Further, it can be checked whether the places currently used as evacuation centers are suitable or not.

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Acknowledgment

Sincere gratitude forward to the Survey Department of Sri Lanka and the Meteorological Department of Sri Lanka for providing all digital data layers and providing rainfall data for the success of our research. Furthermore, I wish to sincerely thank all the lecturers in the Faculty of Built Environment and Spatial Science. Finally, we would like to acknowledge every person who helped us in different ways during the research work.

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