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Flood Inundation Map of Kampung Baru Muafakat Using Satellite Data and GIS Based Analysis

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Abstract

This study uses Geographical Information System (GIS) and satellite data to study the frequently occurring issue of floods in Malaysia, focused on Kampung Baru Muafakat. This study is focused on generating flood extension level in Kampung Baru Muafakat. In this study the appropriate method was used in flood mapping using QGIS to extract contour from Digital Terrain Model (DTM) data using the raster extraction tool, The lowest height in the residential area is identified at 2 meters and the highest height is 14 meters. The Fill & Sinks method is applied to identify catchment areas, has revealed that the catchment area for the study area covers 34.36 km^2. Unsupervised land use classification using the Semi-Automatic Classification Plugin (SCP), that less than 50% of the study area is covered by vegetation indicates a landscape dominated by impervious surfaces such as residential areas, industries and other public facilities. Isohyet maps are generated using the Inverse Distance Weighted method (IDW) based on rainfall data from CHRS, compared and validated with telemetry station data using the Discrepancy Ratio method, the research area has an annual precipitation range of 4065 to 4229 mm. This indicates that there is a significant amount of rainfall throughout the year. This study using a Digital Elevation Model (DEM) based on Triangulated Irregular Network (TIN) for flood depth and area analysis, revealing depths ranging from 0.2 to 1.2 meters, covering 10 out of 64 hectares. The findings add to a complete understanding of flood-prone areas, which will benefit in the development of sustainable urban design and disaster management strategies for Kampung Baru Muafakat.

1. Introduction

Flooding is a natural disaster that often occurs in Malaysia. Every year floods cause damage to property and even worse result in the loss of many lives. Flash floods occur when an area of land that is normally dry is inundated with water. High rainfall intensity, densely developed areas, poorly maintained drainage systems as well as drain and drainage pollution problems are seen to be the main contributing factors to the occurrence of flash floods in urban areas (Shafii, 2021). Flood mapping requires a comprehensive approach that takes into account variables such as flood-prone locations. Geographical Information System (GIS) provides for quick and exact information capture, effortlessly integrating geographical and attribute data to build efficient datasets for analysis (Mustaffa et al., 2016). Remote Sensing is a crucial technology for mapping patterns at large spatial scales. Remote sensing data offer insights into landscape characteristics influencing biodiversity, ecosystem properties, spatial distribution of biodiversity components, natural and human-induced vegetation changes, and the impacts of disturbances and ecological interactions (Matthew et al., 2023).

The critical relationship between lowlands and heavy rainfall plays a central role in these devastating floods. Lowlands, often situated near rivers and streams, face an increased risk of inundation when heavy rains lead to water bodies overflowing into adjacent areas (Safiah et al., 2020). The lack of rainfall data poses a challenge for conducting hydrological analyses essential for flood mapping (Rozalis et al., 2010). The absence of data from this specific location limits the accuracy of flood predictions and hinders the formulation of effective flood management strategies.

This case study aims to achieve three primary objectives. Firstly, it involves determining the catchment area through the identification of contours, providing insights into the geographic boundaries influencing water drainage. Secondly, the study focuses on the analysis of both rainfall and land use data, facilitating a comprehensive understanding of the environmental factors contributing to potential flooding. Finally, the case study intends to generate the flood extension level of the study area by combining information from contour identification, rainfall analysis, and land use data to map and estimate the extent of potential flooding events.

2. Materials and Methods

As shown in the flowchart below Fig. 1, in the initial phase of the study, data collection was carried out, including various data sets such as GIS, satellite imagery, Digital Terrain Model (DTM) data, and rainfall records. After that, the analysis of rain quality data was carried out to see the pattern and trend of precipitation in Kampung Baru Muafakat. The collected data has undergone analysis, GIS-based spatial analysis to explain flood vulnerability. Ultimately resulting in the creation of a detailed Flood Vulnerability Map, showing precisely which areas in the community are most at risk of inundation during a flood event. This comprehensive approach not only improves understanding of flood-prone areas but also facilitates the development of effective urban planning strategies and disaster management initiatives aimed at reducing the impact of floods in Kampung Baru Muafakat.

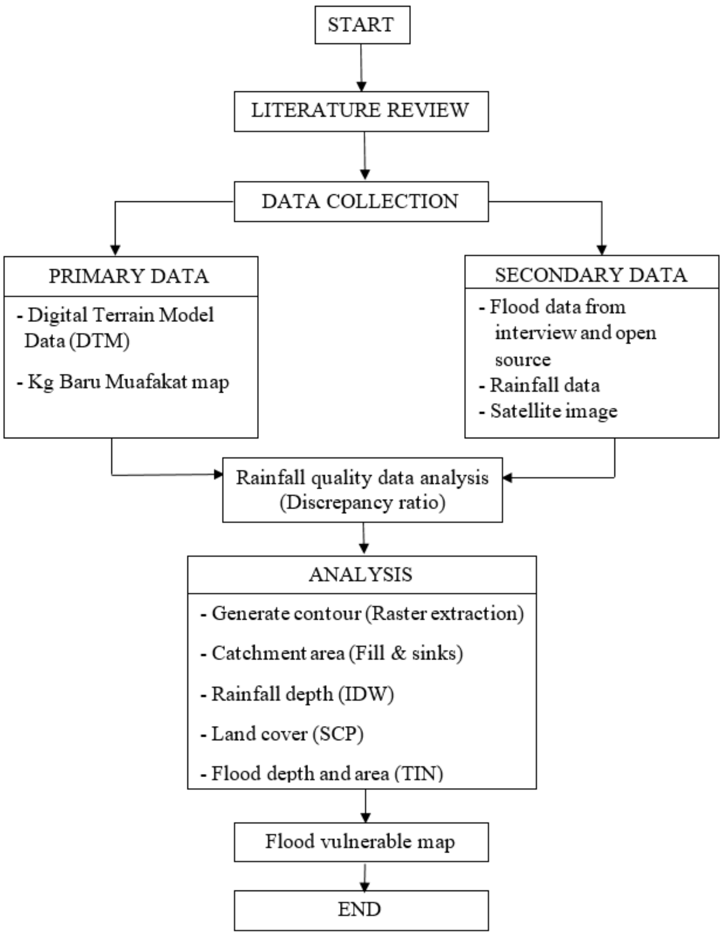

Fig. 1: Flow chart of methodology

2.1 Data Collection

Primary data consists of data from remote sensing image. The data was extracted from the satellite image and combined into value image data. The main data of a DTM is a data that is a sort of elevation representation of the terrain surface. The data is in the form of a raster, which contains values representing each elevation point on the earth's surface.

Secondary data includes characteristics on the study area, such as land use, rainfall data and historical flood records obtain from local authority, and serves as a support to primary data. It is critical in overcoming any constraints in the source dataset by providing a larger context for analysis. Rainfall data refers to information and measurements related to the amount of precipitation, specifically rain that occurs in a particular area over a specified period. This data is typically collected using various meteorological instruments such as rain gauges, radar systems, and weather stations. Rainfall data provides valuable insights into the patterns, distribution, and intensity of rainfall in a given region. Meteorologists, hydrologists, and climate scientists use this data to analyze weather patterns, monitor changes over time, assess drought or flood risks, and contribute to the understanding of broader climate trends.

Furthermore, interview data consists of insights gathered via talks or interviews with local residents. This personal knowledge provides a qualitative dimension to the research by providing vital viewpoints from people in the community. The combination of primary, secondary, and interview data increases the comprehensiveness and reliability of the overall research findings.

2.2 Rainfall Quality Data Analysis

In the realm of hydrological modelling, a Discrepancy Ratio (DR) is employed to measure the deviation between observed and simulated values, determining the suitability of the simulated data. This ratio is crucial for assessing the accuracy of CHRS data against rainfall gauge data. The CHRS Data Portal is a comprehensive system developed by the Center for Hydrometeorology and Remote Sensing at the University of Colorado, Irvine. As indicated by Tayfur & Singh (2005), a DR of 0.0 signifies a precise prediction ($Kxp = Kxm$). Instances of overprediction occur when DR > 0.0 and ($Kxp > Kxm$), while underprediction arises when DR < 0.0 and ($Kxp < Kxm$). The error distribution, falling within the range of -0.3 to 1.0, is symmetric. The DR is computed using the formula provided by Tayfur & Singh (2005):

$$\mathrm{DR} = \log \frac{\mathrm{Kxp}}{\mathrm{Kxm}} \tag{1}$$

2.3 Analysis

The mapping process involves using DTM data obtained from the Interferometric Synthetic Aperture Radar (IFSAR) database for contour extraction. Contour extraction is a method that involves extracting elevation values from DTM data to generate a representation of the study area's topography. This process is executed using QGIS software, employing a raster contour tool with a specified contour interval of 1 meter. During this contour extraction process, elevation values are derived from the DTM data to create contour lines, providing a visual depiction of the varying elevations within the study area.

Additionally, the DTM data is employed to delineate the catchment of the study area. This is achieved through the use of the SAGA Fill Sinks tool, as proposed by Wang & Liu. The tool is designed to identify and fill surface depressions in digital elevation models. The algorithm by Wang & Liu is applied to detect these depressions in the DTM data and subsequently fill them. Filling surface depressions is crucial for accurately representing the natural flow of water across the terrain.

To generate a rainfall isohyet map using QGIS software, data spanning from 2011 to 2021 was used, and this data was acquired from the CHRS Data Portal. The CHRS Data Portal is a comprehensive system developed by the Center for Hydrometeorology and Remote Sensing at the University of Colorado, Irvine. This system is dedicated to providing global satellite precipitation data and related information. Specifically focusing on the Gelang Patah area, annual rainfall data was retrieved from the CHRS Data Portal through their online platform. Its precipitation data available in a point-based format, which captures the spatial distribution of rainfall across the area. Then use Inverse distance weighted (IDW), this method would assign weights to these data points based on their distances from each location on the map, and a weighted average would be calculated to estimate the rainfall values at unsampled locations.

To determine land use in a specific study area, the first step involves acquiring a satellite image from an open-source platform like Landsat 8. Navigating to the USGS Earth Explorer website, the chosen scene can be downloaded, providing multispectral data with suitable spatial resolution for accurate land use analysis. The Semi-Automatic Classification Plugin (SCP) enhances its capabilities by providing tools specifically designed for semi-automatic image classification. This plugin streamlines the process of generating land use supervised and unsupervised classifications from satellite imagery. Use an unsupervised classification due to its simplicity and fast processing, as it offers a quick and easy way to analyze land use. The reliability of this approach was confirmed by Oyekola et al. (2018), whose study showed its effectiveness in accurately distinguishing between soil, vegetation and water. The simple nature of unsupervised classification, together with efficient results, makes it a practical choice for tasks that require rapid assessment of different types of land cover.

In the process of estimating the water surface height during flooding, analysis of the DTM along the border is conducted. Based on the findings of Brown et al. (2016), it is likely that the water surface in flooded areas has flat features due to the mild slope and flood stream within the region. Consider the flood level to be at 3 meters, based on the danger level in Sg. Gelang Patah is 3 meters to overflowing into the surrounding areas. To ensure the height of the flood water surface, the TIN (Triangulated Irregular Network) Interpolation method is used. This method, previously used by Cohen et al. (2018), relies on a nearest neighbour algorithm that starts at the boundary of the floodplain. By taking advantage of nearby data points, the TIN Interpolation method facilitates the estimation of elevation values for the flood water surface.

Following the interpolation, the flood level DEM is overlaid with the original DEM of the study area. This overlay operation serves to delineate the flood boundary by identifying areas that have been impacted by the overflow. Subsequently, the depth of flooding is determined for each pixel within the flooded area. This is achieved by calculating the difference between the DEM value at a given pixel and the corresponding flood water surface elevation.

2.4 Flood Vulnerable Map

The flood map produced by the integrated model using input from remote sensing data and GIS analytical tool. This approach integrates information from four maps, rainfall isohyet map, elevation map, catchment map, and land use map each of which contributes critical parts to the overall flood mapping model. The maps used to create flood maps include a wide range of parameters that have a substantial impact on the amount and characteristics of flooding. Elevation, land use, catchment, rainfall, flood depth, and area are all predictors. The construction of the flood maps involves a GIS based overlay process. This technique entails layering all the maps and assigning weights to each layer based on its relative importance in influencing flood conditions. The GIS overlay process involves assigning scores or weights to each cell in the GIS layers, and these scores are combined to produce a composite map that represents the severity of flooding across the study area.

3. Result and Discussion

The Results and Discussion section of the study presents a comprehensive analysis of the factors that affect flooding in Kampung Baru Muafakat. It begins with an examination of rainfall quality data, explaining the patterns and trends of precipitation in the study area and its relationship to flood risk. Elevation analysis highlights elevation ranges and identifies low-lying areas prone to flooding. Using methodologies such as the Fill & Sinks method, catchment areas are delineated, providing insight into surface water flow and flood spread. Analysis of rainfall depth data reveals variations in precipitation levels and their implications for flood scenarios. Land use patterns are explored, emphasizing the prevalence of impervious surfaces and their role in exacerbating flood risk. Finally, the generated flood map integrates information from multiple analyses, visually depicts flood-prone areas and informs disaster preparedness and urban planning strategies. This holistic approach increases the understanding of flooding in Kampung Baru Muafakat and provides valuable insights to reduce its impact on the community.

3.1 Rainfall Quality Data Analysis

In order to ensure the accuracy and reliability of the rain isohyet map, a comparative analysis of rainfall depth in 2022 was carried out by combining CHRS-derived data with measurements obtained from telemetry stations. Telemetry stations serve as ground-based reference points, offering real-time and on-site rainfall measurements. By comparing remote sensing data from CHRS with ground truth measurements from telemetry stations, researchers aim to validate and refine the accuracy of isohyet maps.

Rainfall depth from isohyet map year 2022 = 4000 mm
Rainfall depth from telemetry station year 2022 = 2300 mm

$$DR = \log(2300/4000) = -0.24 \quad (1)$$

The error distribution, being in the range of -0.3 to 1.0, meets the discrepancy ratio requirement.

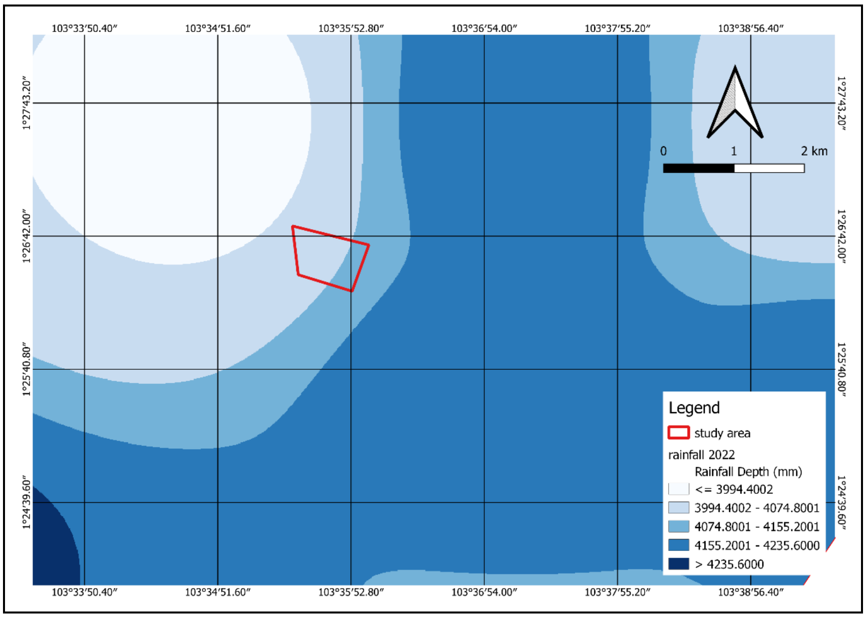

Fig. 2 Rainfall isohyet map for the year 2022

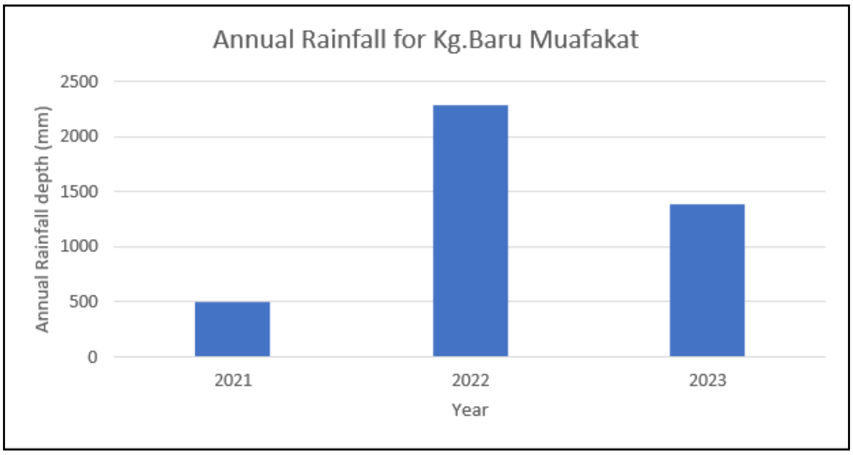

Fig. 3 Annual rainfall obtained from the telemetry station in 2022

3.2 Elevation of Kampung Baru Muafakat

In Fig. 4, the elevation map of the Kg Baru Muafakat area reveals critical information about the topography of the residential zone. The lowest height in the residential area is identified at 2 meters and the highest height is 14 meters. This is a significant observation, especially in the context of flood risk. The surrounding low-lying areas are indeed more vulnerable to flooding, especially when the water level in the Gelang Patah River rises and overflows. The principle at play here is that areas located at lower elevations face a higher risk of inundation, as water tends to flow faster from higher to lower elevations. As a result, these low-lying areas may experience faster and more severe flooding when there is an overflow of water from Sungai Gelang Patah.

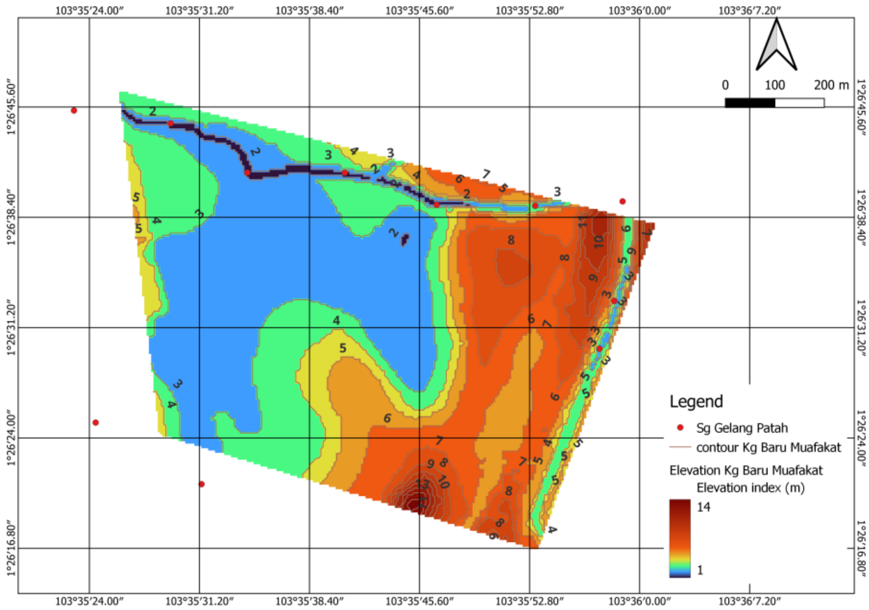

Fig. 4 Elevation of Kg Baru Muafakat

3.3 Catchment Area

QGIS analysis using the Fill Sink method by Wang & Liu has revealed that the catchment area for the study area covers 34.36 km^2 as shown in Fig. 5. The catchment area serves as an important zone designed to capture and retain rainwater, allowing water from higher areas to flow to lower areas and finally exit through Sg Gelang Patah. In hydrology, the concept of a catchment area is fundamental, representing the terrain where precipitation is collected and then drained. In this context, elevated areas within the catchment area act as sources of water flow, guiding rainwater down the hill. During rain events, water accumulates in this catchment area and then follows the drainage channel directly to the outflow, Sg Gelang Patah. Kg Baru Muafakat area is located in the middle of this catchment area, where water from the higher surrounding areas gathers before flowing out to Sg Gelang Patah. This causes the Kg Baru Muafakat area to be vulnerable to flooding. The accumulation and concentration of water from higher ground, combined with its location in the middle of the catchment, makes it vulnerable to flooding during heavy rain events.

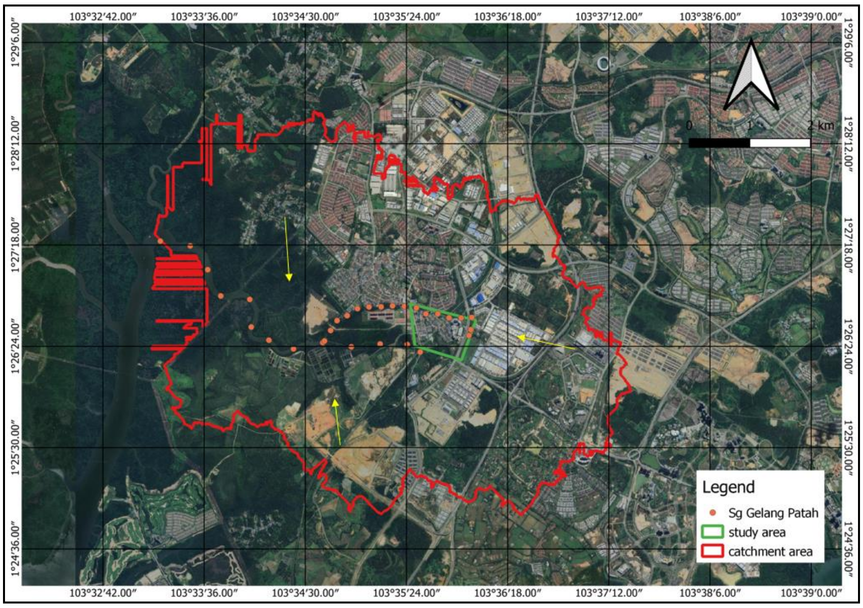

Fig. 5 Catchment area of Kg Baru Muafakat

3.4 Rainfall Depth

According to the rainfall isohyet map Fig. 6, the Kampung Baru Muafakat has an annual precipitation range of 4065 to 4229 mm. This indicates that there is a significant amount of rainfall throughout the year, indicating a high possibility for intense and long precipitation events. Understanding this range is critical in the context of assessing flood risk. Higher yearly rainfall totals within this range indicate that the research area is prone to receiving large amounts of water throughout the year.

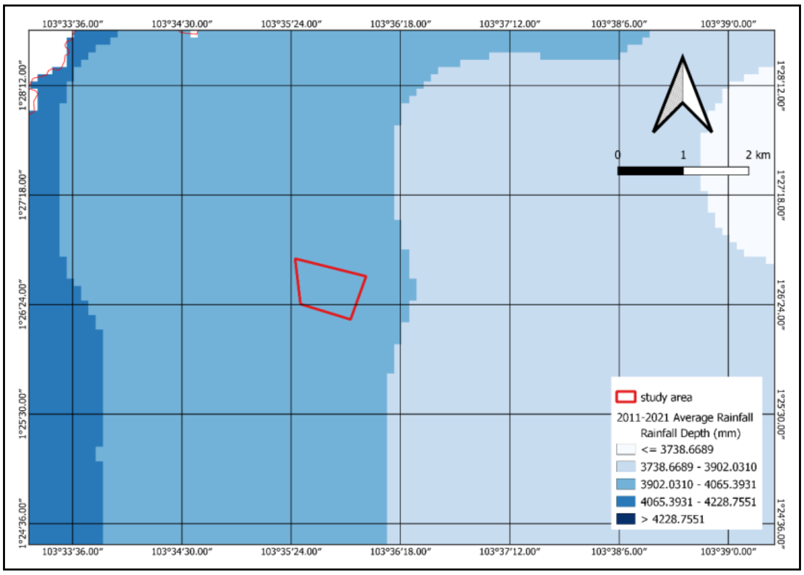

Fig. 6 Rainfall isohyet map of Kg Baru Muafakat region

3.5 Land Use

The observation based on Fig. 7, that less than 50% of the study area is covered by vegetation indicates a landscape dominated by impervious surfaces such as residential areas, industries and other public facilities. The prevalence of impervious surfaces, which do not allow water to infiltrate into the soil, can have profound implications for the hydrology of the area, especially in the context of flood frequency. Impermeable surfaces limit the natural infiltration process, where water is absorbed into the soil. In areas with extensive impervious cover, rainfall is more likely to result in increased surface runoff rather than absorption. This high runoff contributes to the volume and speed of water flowing across the landscape. The composition of land cover plays a pivotal role in assessing flood susceptibility, as areas with reduced vegetation are generally more prone to flooding, as noted by Rahman et al. (2021).

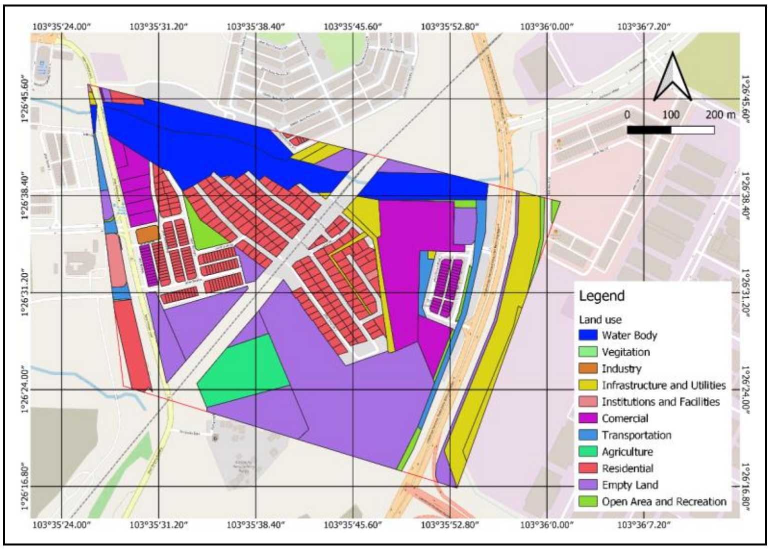

Fig. 7 Land use data of Kg Baru Muafakat

3.7 Vulnerable Map

By combining the spatial data of elevation, catchment area, rainfall intensity, land use, flood depth and area a map of flood delineation has been created. Fig. 8 provides a detailed visualization of the extent of flood on Kg Baru Muafakat, including the impacted area as well as the depth of the water. The data reveals that approximately 10 hectares, out of the total 64 hectares, experienced flooding highlighting the severe inundation within the residential zone. The floods damaged roughly 80 residences and 10 commercial sites, with water depths reaching 1.2 metres and 0.2 metres, respectively. Furthermore, the area's infrastructure and utilities were also flooded to a depth of 0.2 metres. This is critical because it implies the possibility of damage and interruption to critical services and facilities such as roads, utilities, and other public infrastructure.

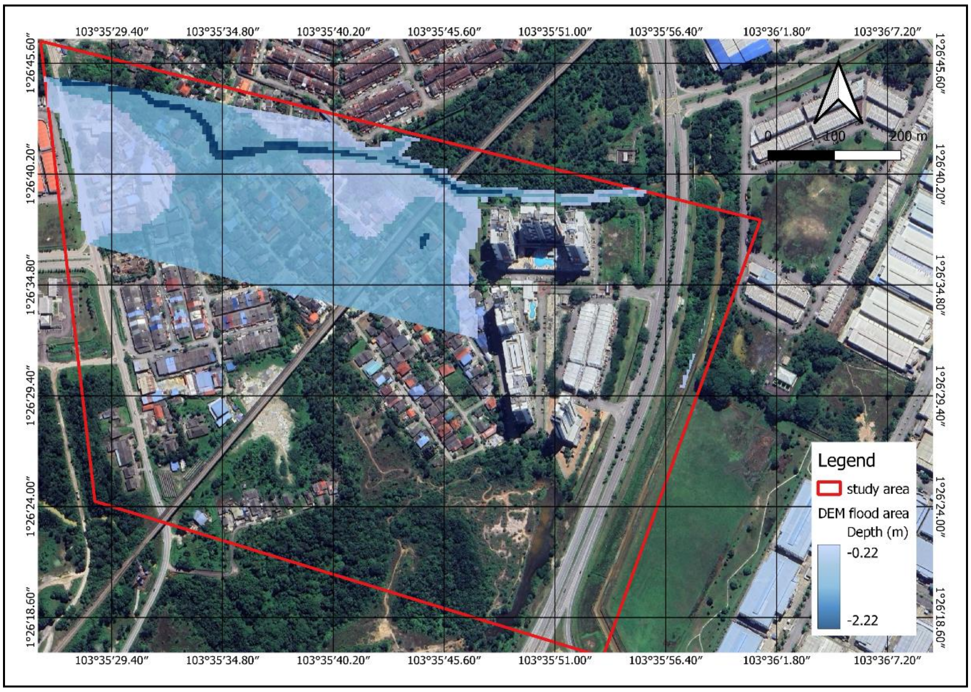

Fig. 8 Flood delineation of Kg Baru Muafakat

Kg Baru Muafakat's vulnerability to floods is influenced by a number of factors, which are revealed by a thorough study of the land's terrain, hydrology, and topography. The elevation map highlights a diverse terrain, with a significant range in elevations from 2 to 14 meters, creating conditions conducive to flood risk, particularly in lower-lying areas susceptible to river overflow. The identification of a catchment area through QGIS analysis show that natural drainage pathways in collecting and directing rainwater toward Sg Gelang Patah. Kg Baru Muafakat, positioned centrally within this catchment, is exposed to heightened flood risk due to the concentrated flow of water from higher elevations. The observed less than 50% vegetation coverage highlights the prevalence of impervious surfaces, limiting natural infiltration and promoting increased surface runoff.

4. Conclusion

This study is crucial because it offers a thorough understanding of the variables affecting Kg Baru Muafakat's vulnerability to flooding. The elevation map's depiction of the topography, ranging from 2 to 14 meters within the residential area, show the significant flood risk, particularly in lower-lying regions susceptible to overflow from the Gelang Patah River. A catchment area of 34.36 km^2 is identified by the QGIS study using Wang & Liu's Fill Sink tools. This catchment is crucial for collecting rainwater and directing it towards Sg Gelang Patah, making Kg Baru Muafakat vulnerable to flooding due to concentrated water flow from higher elevations.

A comprehensive flood delineation map is the result of integrating elevation, catchment, rainfall, land use, and flood data. This map is useful for emergency responders and local governments. This study offers evidence-based insights for targeted mitigation strategies, urban planning and resilient community development. By identifying vulnerable areas and quantifying the impact of flooding, this study improves disaster preparedness, and contributes to the development of a sustainable urban environment in flood-prone areas. This study is not only academically important but also has significant benefits for local authorities, emergency responders and society in general. From this study all the objective of identify contours to predict floods area and estimate flood level based on real time data and create flood delineation map of Kg Baru Muafakat are achieve. The result of the analysis shows the completion of each objective and provided a data that can be used in the future studies.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

This journal requires that all authors take public responsibility for the content of the work submitted for review. The contributions of all authors must be described in the following manner:

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Author X, Author Y;* ***data collection:*** *Author Y;* ***analysis and interpretation of results:*** *Author X, Author Y, Author Z;* ***draft manuscript preparation:*** *Author Y, Author Z. All authors reviewed the results and approved the final version of the manuscript.*

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