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Water Surge Risk Mapping Using GIS-Based Spatial Multi-Criteria Decision Analysis Approach

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Abstract. Water surge is a frequent natural disaster in Malaysia, with about 186 areas nationwide identified as being at risk. The absence of an updated water surge risk map for recreational areas has led to numerous deaths, property damage, and environmental destruction. Lack of assessment of the physical environment using geospatial technology towards water surge occurrence has led to less effective disaster management and mitigation strategies related to water surge in recreational areas. The aim of this study is to develop a recent water surge risk map using geospatial technology, with a focus on a recreational area in Pahang, Malaysia. The process entails gathering geographical data and evaluating data using GIS-based Spatial Multi-Criteria Decision Analysis (SMCDA), which is generally based on the Analytic Hierarchy Process (AHP) model in ArcGIS Pro. A water surge risk map is developed by not only visualizing water surge factors but also weighting each relevant contributing factor, such as terrain elevation, land use type, and rainfall. The finding of the study suggests that Sg. Pandan Waterfall area falls into medium-risk water surge zones due to combination of three main factors including terrain elevation, land use or rainfall pattern. The map is crucial to enhancing resource allocation, disaster planning, and community resilience where water surges have not previously been mapped. This study not only helps in raising awareness about water surge risks but also supports SDG 14 and SDG 15 initiatives as well as building safe communities.

1. Introduction

Waterfalls are more than just beautiful sights as they are important indicators of a river's health and the overall well-being of the ecosystem. Their presence signifies a healthy river environment, supporting the growth of vegetation along the riverbanks. Waterfalls attract a wide variety of life, including people, plants, animals, reptiles, and birds. These ecosystems thrive because of the continuous flow of water from the falls. However, waterfalls are threatened by the northeast monsoon and various human activities, such as land use changes and deforestation, which have led to decline its function and build a water surge (Samah, 2022). Water surge or headwater defines as phenomena in which an enormous amount of water waves arrives suddenly from the upstream area of the river (Selvam, 2023). The water flow has the capacity to transport various debris, including garbage and wood, found in the river, and will collide with any obstruction it encounters. Water surge can rise between one to two meters within five to ten minutes and can move at speeds ranging from 2 to 10 meters per second (Mansor, 2022).

Sungai Pandan Waterfall, also known as Panching Waterfall, is in the Malaysian state of Pahang, near Kuantan. This natural waterfall is a popular recreational destination for locals. The area is part of the Pandan Recreational Forest Reserve. The waterfall, as shown in Figure 1, consists of several levels, making it suitable for both adults and children. Sungai Pandan is 19.3 kilometer long and 17 meter wide. It is located approximately 25 km from Kuantan town, at Felda Panching Selatan, Pahang, Malaysia, with coordinates 3°47'27.8"N 103°08'40.7"E (Maps, 2024). In 2018, the population of this area was 1,200 people (Hassan, 2018), and it is estimated to grow to 7,000 by 2024. As Sungai Pandan Waterfall, Kuantan is situated in a tropical region, it experiences a warm and humid climate throughout the year. The Northeast monsoon season, typically from November to March, brings heavier rainfall to the area.

Figure 1. The top view of upstream, midstream and downstream of Sungai Pandan Waterfall captured by drone DJI mini 3 Pro.

Malaysia has more than a hundred beautiful waterfalls, including Sungai Pandan Waterfall (Shamel, 2019). Waterfalls are more than just beautiful as it indicates the health of a river and its ecosystem. However, this natural view can also be dangerous due to heavy precipitation, land use changes, and deforestation (Samah, 2022). Thus, this study aims to produce Geographical Information Systems (GIS)-based risk map based on these factors associated with water surge using AHP. Conventional risk maps are typically created using older technologies and methods, such as manual surveying and cartographic techniques. Traditional methods, often involving manual measurements, are susceptible to human error. Variability in measurement accuracy can arise due to the human element involved in data collection (Tan, 2023). By combining remote sensing and GIS technologies, this study facilitates a more comprehensive and continuous evaluation of water surge, covering a larger area and providing more frequent updates. The integration of remote sensing technology and GIS for water surge assessment in Sungai Pandan Waterfall holds significant importance for various stakeholders and carries wide-ranging implications for environmental protection, as reflected in the National Disaster Management Agency's motto: "Managing disasters, save lives" (Moh, 2012).

This study seeks to underscore its importance by emphasizing how it can enhance water surge monitoring. Remote sensing data, particularly satellite imagery, provides insights into historical water surge patterns at large spatial scales, eliminating the necessity for costly and labour-intensive field campaigns. Additionally, remote sensing data is accessible from various sources, including freely available datasets, thereby reducing the financial burden associated with data acquisition. The AHP model has been built to identify and map areas of high risk of water surge in Sungai Pandan Waterfall.

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AHP is a multi-criteria decision-making method which integrates several features/conditioning factors such as precipitation, slope, elevation, land use changes and deforestation to map water surge risk. Vulnerability map and hazard map has been generated from all these factors. Using a machine learning model directly on the input of the AHP model reduces the computational steps to create a risk score and weight-age (Omdena, 2021).

Risk map with AHP approach enhances effectiveness in water surge assessment. Satellite imaging covers vast regions, offering a comprehensive and reliable view of water surge dynamics. Compared to traditional data collection methods that may involve physically visiting multiple locations, this efficiency in data collection minimizes time and effort requirements. Furthermore, GIS technology facilitates effective management, integration, and analysis of data, enhancing the overall assessment process.

2. Literature Review

Every year, unfortunate incidents occur at waterfalls around the world, claiming lives and leaving behind a trail of devastation for families and communities. The presence of a water surge can also pose some challenges. In 2022, 186 waterfalls and recreational areas were identified as high-risk zones for water surges across the country (Wahid, 2022). These areas are especially vulnerable to sudden, dangerous water surges after heavy rainfall, posing significant risks to visitors. Erosion caused by strong water flow can damage ecosystems in the surrounding area, including plants and animal habitats (Samah, 2022). The strong currents associated with water surge can sweep people away and trap people in deep or hazardous waters, complicating rescue efforts and increasing the risk of drowning.

2.1 Threats of Water Surge on Environment, Social and Economy

As early year case occurred in February 2024, the body of the first victim of the water head tragedy was found in Sungai Kenjur, Kampung Poh, who sacrificed himself to save four surviving family members (Adnan, 2024), as shown in Figure 2. Recently, several water surge incidents have occurred in Malaysia, causing significant environment, social and economy impacts. Tragically, in Lembah Mak Sina, Lahad Datu, a surge in May 2024 claimed three lives when individuals were swept away while trekking. The victims were found trapped under debris, highlighting the fatal risks associated with such incidents (Rashid, 2024). In Slim River, Perak, a sudden surge trapped 19 peoples at Risda Eco Park and led to the evacuation of 170 residents. The water surge also caused severe damage to three bridges in the area (Marzuki, 2024), as shown in Figure 3. Similarly, heavy rainfall triggered a surge at Kolam Puteri Waterfall, Gunung Ledang, stranding 60 hikers, all of whom were later rescued (Ahmad, 2024). Another surge occurred at Sungai Pisang, Selayang, where fast-rising water posed a threat to visitors, though no major casualties were reported (Ramayah, 2024). Moreover, the incident of water surge at the Kepala Tujuh Waterfall in Langkawi resulting in damage to several vehicles, as shown in Figure 4.

Figure 2. News of three death caused by water surge at Sungai Kenjur, Bidor.

Figure 3. Slim River's bridge collapsed due to water surge at Slim River, Perak.

Figure 4. Impact of property damage at Kepala Tujuh, Langkawi after water surge.

2.2 Usage of Remote Sensing for Water Surge Risk Map

Recently, there are no specific studies dedicated to risk mapping for water surge disasters, however, other disasters such as earthquake, storm surges, and landslides have been the subject of investigation. Several studies have effectively integrated GIS and remote sensing for mapping water surge risk. One notable study conducted in India involved the preparation of a land use/land cover (LULC) map for the Sundarbans Biosphere Reserve (SBR) using a Landsat 8 image acquired in January 2017 under optimal atmospheric conditions with minimal cloud cover (Mehebub and Sajjad, 2019). The study area was analysed using a supervised classification technique to delineate various LULC classes, including wetlands, swamps, vegetation, mangroves, cropland, beaches, and settlements. The classification accuracy was assessed through an error matrix and the Kappa coefficient (k), resulting in an overall accuracy of 91.4% and a Kappa value of 0.92.

For regression analysis, the natural disasters in Indonesia are observed by using of remote sensing imagery from Landsat-8 and Sentinel-2 (Hakim and Lee, 2020). A damage map was generated by processing pre- and post-earthquake satellite images together with the artificial neural network classifiers and a decorrelation method. Damage maps were developed from these post-earthquake estimates and compared with field data, accounting for the level of agreement between artificial neural network consists of support vector machine (SVM) outcomes to extract a percentage harmony driving to produce four earthquake damage maps in all. Conformity analysis showed that the Landsat-8 image is more accurate (85.83%) than Sentinel-2 (63.88%) imagery of (Hakim, Wahyu Luqmanul, 2020). Information generated from the post-earthquake damage map can be used to evaluate the spread of seismic damage induced by the Palu earthquake which is essential for prevention of similarity in future seismic occurrences. Additionally, weightages of various land use (LU) classes consisting of water, urban area, bare land, cropland, agricultural areas, shrubs; forests and herbaceous were discussed in the Galikesh River Basin (Farhadi and Najafzadeh, 2021). The land use index was constructed by means of

time-series Landsat-8 images validated using a support vector machine (SVM) in the Google Earth Engine (GEE) and with an overall accuracy (OA) of 95 % (Farhadi, Hadi, 2021).
The second study aimed to detect land cover changes in the Klang region of Selangor, Malaysia, via diversification of machine learning techniques. The performance of Support Vector Machine (SVM), Machine Learning (ML) and Neural Networks (NN) was then tested on 10 % training set size as well as on 90 % training sets. 10% training data %90 training data SVM 92.67% 93.16% (Ahmad et al., 2019) This was followed by ML with 89.98% and 90.61% while the lowest accuracy was achieved through NN with a score of 60.64% and 21.78%. Even though for both SVM and ML, the accuracy got better as the training sizes grew (90%) however there is a huge drop in NN's success rate as the training set increases. Consequently, in this case, SVM was able to demonstrate higher reliability and consistency for land cover change detection.

3. Materials and Methodology

Figure 5 shows the general flowchart of the study which shows the technical flow of the work to achieve all the objectives using appropriate data, materials and techniques.

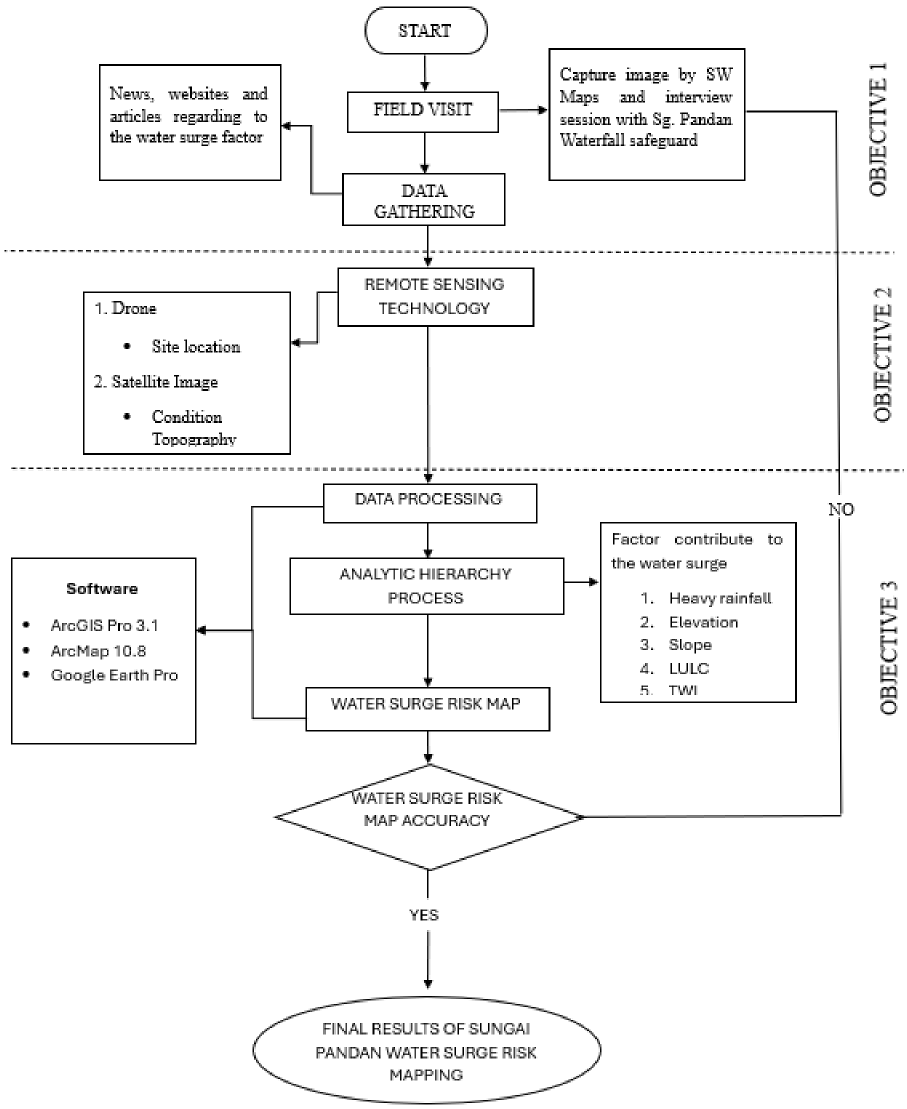

Figure 5. Flow chart of the study

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3.1 Data Collection

Both primary and secondary data for this study was gathered. The field trip aimed to gather data directly from the research area. By focusing on the mapping of water surge factors and waterfall boundaries, this study focused on the water surge in Sungai Pandan, Kuantan, Pahang. After the field visit, secondary data was collected using remote sensing satellites, specifically the Landsat 8 Operational Land Imager (OLI). The site visit was conducted to compare and verify the survey results. During the visit, several tools were required, including drone and mobile phone, as shown in Figure 6. The use of drone technology allowed for aerial monitoring and observation of the site, capturing images and providing a more detailed view of the current condition of the field area. Additionally, two mobile applications were used for this project: SW Maps and UAV Forecast, as shown in Figure 7. SW Maps offers a simple and cost-effective way for individuals and organizations to accurately collect location data. Meanwhile, UAV Forecast assists drone pilots in determining if it's safe to fly by providing real-time weather updates, including wind speed, temperature, visibility, and cloud cover, along with forecasts at different altitudes. It helps pilots avoid unfavourable weather and ensures safer, more efficient flights.

Figure 6. Equipment used at the filed site

Figure 7. Mobile applications at the field site

The secondary data for this study was obtained using remote sensing techniques, specifically through satellite imagery. This process utilized moderate spatial resolution of multispectral satellites, including Landsat 8 OLI (L8), as shown in Figure 8. However, this study only used Landsat 8 OLI with low cloud coverage (<20% per scene). Low scene cloud coverage is preferred in satellite imagery because it ensures a clearer view of the ground, which is critical for accurate analysis and data quality. When the cloud cover is minimal, land features such as forests, water bodies, and other details are more visible, making it easier to observe and analyze them without interference. The spectral bands of these satellites, each with distinct wavelength ranges, provide valuable data for various applications, such as assessing elevation, slope, land cover, detecting environmental changes, and studying natural phenomena. Landsat 8's OLI-2 spectral bands offer critical insights into Earth surface characteristics, enabling detailed analysis of various processes. Similarly, Sentinel-2 on the global level data is widely used in land cover mapping (LCM) for change detection, disaster management and for environment monitoring. The two satellites have an average revisit time of 5 days at the equator, which makes it possible for all regions on Earth to be scanned. Their imagery has spatial resolutions from 10 to 60 meters, varying with the spectral band being viewed.

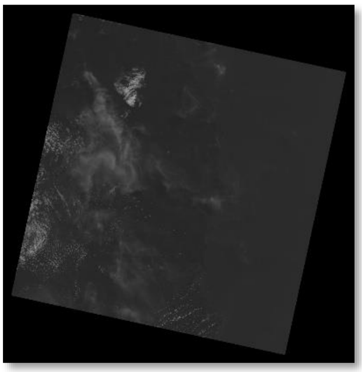

Figure 8. Raw spectral band 1 of Landsat 8 OLI

3.2 Data Processing

As all the data collected whether primary or secondary was fundamentally critical to underpin the objectives of the study, processing became one of the most crucial parts of this research. To maintain data accuracy, the primary data was processed and rechecked corresponding to secondary data. In the pre-processing stage, were obtained Landsat 8 satellite images that are available into the site of United States Geological Survey (USGS) for three years: 2014, 2019 and 2024. Data processing and subsequent results that matched the purpose of study were obtained by using several data analysis tools namely, ArcGIS Pro, ArcMap, Google Earth Pro; and its supported server service like Google Earth Engine. Merging all spatial data sources into one integrated dataset the idea was to make the image error-free and improve its quality through methods like geometric correction, radiometric calibration, sub setting of images, and atmospheric corrections.

The processing phase, being the most critical in analysis as this was where all the data had been collapsed to deliver results which fitted into the goals of the study. Data from the site visit was subject to a specific process before progressing to the next stage. For improved image quality and extraction of water surge risk mapping, the solution which was applied is using specific spatial analysis tools such as ArcGIS Pro Google Earth Pro to meet the project requirements. The AHP method will also be helpful for creating a water surge risk map after the data has been processed. The pairwise comparison is central to the AHP method, helping to understand both its theory and application. In a multi-criteria decision-making (MCDM) process, AHP uses a preference matrix to determine the weights of criteria by comparing them with a scale of relative importance as shown in Figure 9. Using the pairwise comparison matrix, AHP calculates the weight for each criterion, as shown in Figure 10. To validate results from AHP, the consistency ratio (CR) is calculated using the formula, CR=consistency index (CI)/random consistency index (RI). RI values are referred to the dimension of the matrix (Golden and Wang, 1990). Meanwhile, CI is value obtained through the following formula: $(\lambda_{max} - n)/(n\text{-}1)$, where λ_{max} is the maximum eigen value of the pairwise matrix and n is the number of factors that are considered for water surge occurrences. Lower than 0.10 CR value means the result is acceptable.

Verbal judgment	Numeric value
Extremely important	9
	8
Very Strongly more important	7
	6
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1

Figure 9. Pairwise comparison scale

	TWI	DEM	SLOPE	LULC	RAINFALL
TWI	1	1/7	1/6	1/5	1/8
DEM	7	1	1/6	5	1/7
SLOPE	6	6	1	5	1/7
LULC	5	1/5	1/5	1	3
RAINFALL	8	7	7	1/3	1

Figure 10. Pairwise comparison matrix for the study

4. Results and Discussion

Sungai Pandan Waterfall, as shown in Figure 11, is located in a natural and preserved environment, nestled within the lush forests of Hutan Lipur Sungai Pandan near Kuantan. The waterfall is a popular destination for recreation, attracting visitors with its clear, cool waters and scenic surroundings. The midstream section of the river remains relatively untouched, providing a pristine environment for activities such as swimming and picnicking. However, a water surge in January 2021 increased the depth of the midstream, leading to the tragic drowning of two UMPSA students in April 2021 (Ramli, 2021).

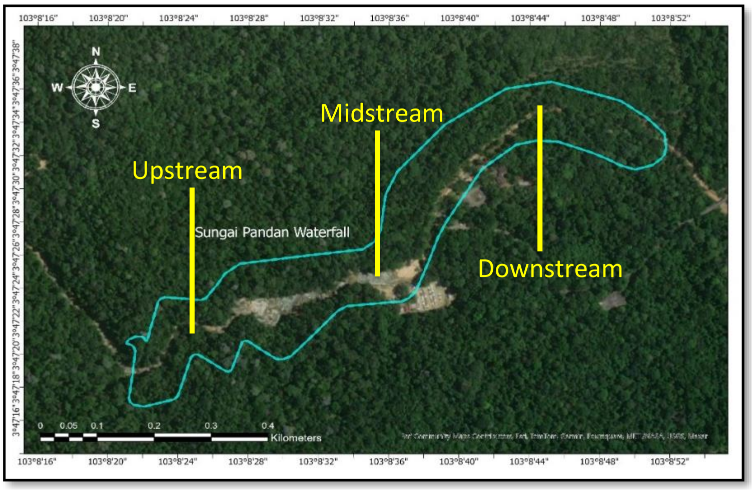

Figure 11. Area of Sungai Pandan Waterfall as shown through ArcGIS Pro

4.1 Weightage of influencing factors

Figure 12 showcases slope values within the area surrounding Sungai Pandan Waterfall. Utilizing a color gradient from dark green to dark red, the map effectively represents increasing slope values, which range from 2.1 to 27.2. This gradient visually communicates the topography of the region, with the steepest slopes, indicated by dark red areas, concentrated in the central region of the winding path leading to the waterfall. The steep slope promotes a strong flow velocity from the upstream to the midstream, resulting in an increase in water depth in the midstream area.

Meanwhile, Figure 13 illustrates a Digital Elevation Model (DEM) of the Sungai Pandan Waterfall area, providing a clear representation of the varying topography surrounding the waterfall. The DEM data, color-coded for clarity, highlights different elevation levels within the terrain. The highest elevation class, marked in red, at the upstream range from 119 to 141 meters and are likely found in steeper, more rugged areas, possibly representing the cliffs or highland areas adjacent to the waterfall. As the colours transition from red to orange and yellow, the elevation decreases, showing more moderate to low-lying areas.

The Topographic Wetness Index (TWI) is often utilized to evaluate the influence of topography on hydrological processes, highlighting the potential for groundwater infiltration due to landscape features. In the context of the AHP, TWI can be an important factor for decision-making related to water management and environmental planning. The TWI map for the Sungai Pandan Waterfall area, as shown in Figure 14, shows how water accumulates in various parts of the landscape. The map uses different shades of green to represent areas with varying levels of water accumulation. Dark green areas represent higher ground or steeper slopes where water quickly flows away, while lighter green areas indicate lower, flatter sections, such as riverbanks or the base of the waterfall, where water tends to pool.

Rainfall is a primary source of water in the hydrological cycle and serves as a biggest key factor influencing to the water surge. For this study, Figure 15 shows average annual rainfall data from 2014 was utilized from Google Earth Engine and the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) daily data since heavy precipitation during northeast monsoon, revealing annual precipitation that varies from 35.001 mm to 672 mm. A spatial distribution map of rainfall was created using the Inverse Distance Weighting (IDW) interpolation method. Based on the maximum and minimum rainfall values, the data was reclassified into five categories: Very Low (35.001–170 mm), Low (170.001–303 mm), Moderate (303.001–427 mm), High (427.001–524 mm), and Very High (524.001–672 mm). The upstream shows the highest value than midstream and upstream. This will cause a very high velocity flow to the downstream forming a water surge. The infiltration rate is influenced by both the intensity and duration of rainfall; high-intensity, short-duration rainfall tends to result in less infiltration and more surface runoff, whereas low-intensity, long-duration rainfall promotes greater infiltration compared to runoff. In the context of AHP, higher weights are assigned to areas with increased rainfall, as they are critical for assessing groundwater recharge and flood risk. Figure 15 illustrates the spatial interpolation map of rainfall for the Sungai Pandan Waterfall. The interpolation result shows that the dark blue highlights the heavy rainfall observed upstream, which leads to an increase in the velocity of the waterfall. In contrast, the downstream area exhibits lower rainfall distribution, indicated by a soft blue color.

Figure 16,17 and 18 show the results of supervised classification for the Land Use and Land Cover (LULC) for the Sungai Pandan Waterfall area across three distinct years: 2014, 2019, and 2024, respectively. Different colours represent various land types: light blue indicates water, representing the river and waterfall; beige denotes open areas such as paths; magenta marks buildings; teal signifies shrubland, depicting areas with low vegetation; and green represents dense forest around the waterfall. This map is instrumental in understanding land use patterns and is valuable for effective area management. In 2019, the majority of the waterway was covered by forest. By 2024, many open areas identified in 2019 have been developed into buildings downstream. Additionally, the waterway appears clearer in 2024 than in 2014 and 2019, attributed to advancements in satellite technology, higher resolution data, and improved processing algorithms in Google Earth Pro. Regular updates to imagery databases further enhance the clarity and detail of the Earth's surface.

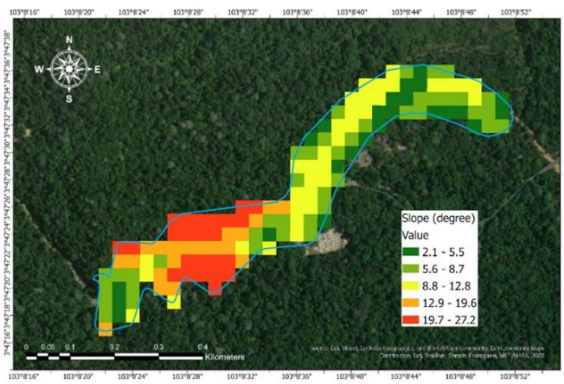

Figure 12. Slope map of study area

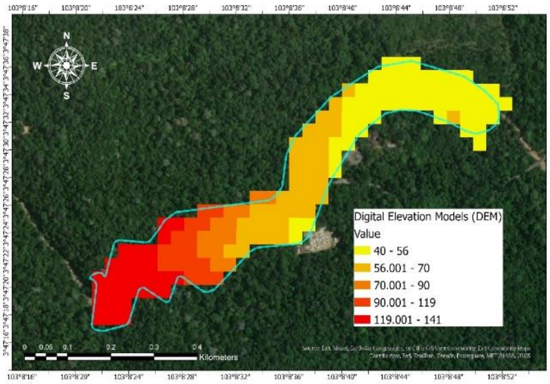

Figure 13. Digital Elevation Model (DEM)

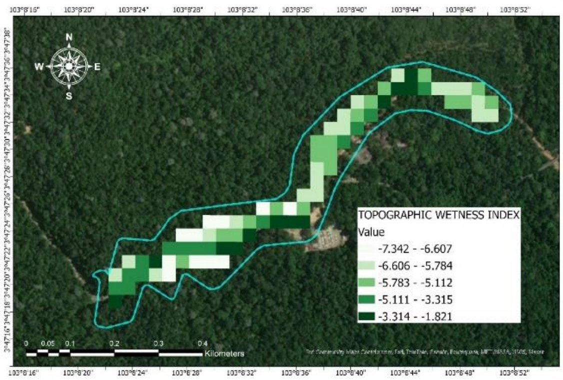

Figure 14. Topographic Wetness Index (TWI)

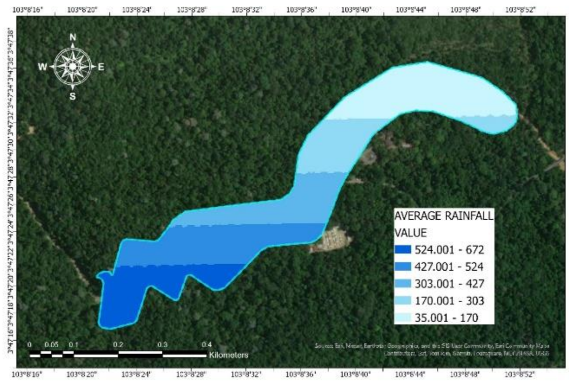

Figure 15. Rainfall data for 2014

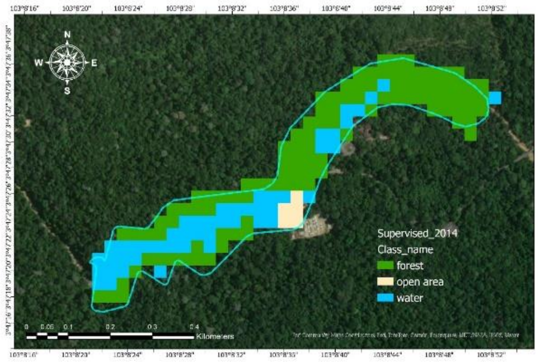

Figure 16. Land Use Land Cover by using Support Vector Machine for 2014

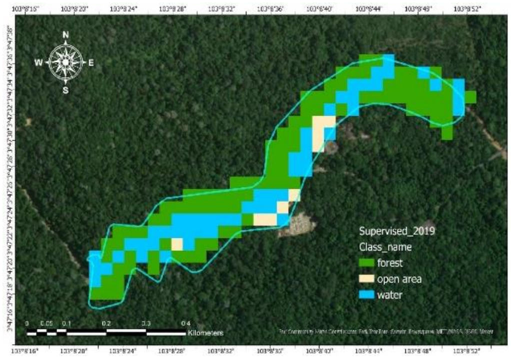

Figure 17. LULC using SVM for year 2019

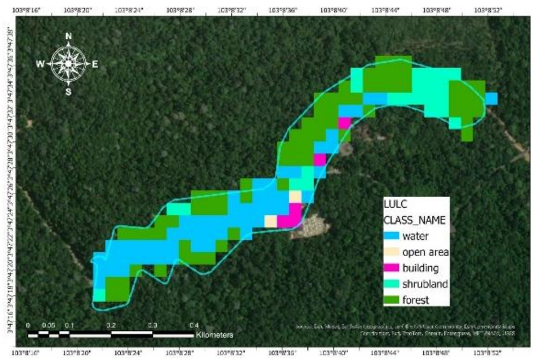

Figure 18. LULC using SVM for year 2024

4.2 AHP GIS Based Approach for Water Surge Risk Map at Sg. Pandan Waterfall

The study used a multi-criteria decision-making process integrating the AHP with GIS to develop a GIS-based approach for water surge risk mapping in Sungai Pandan Waterfall. The risk of water surges is influenced mostly by the slope, elevation, Topographic Wetness Index (TWI), rainfall and land use/land cover (LULC). They take on particular importance in studying the hydrological dynamics of this area, notably with regard to events such as the flood disaster of April 2021. Each of these factors would be represented in Universcale as a GIS layer (data from DEM for elevation & slope, TWI for understanding of water accumulation patterns etc), and historical rainfall data (using spacial interpolation techniques s.a Inverse Distance Weighting), and LULC maps generated from satellite images. Table 1 show pair-wise comparison matrix, and final weights (w_i) for flood susceptibility criteria of Sungai Pandan Waterfall.

Using AHP, relative weights of each factor to the surge risk of water to be allocated is ranked once the GIS layers are prepared. Rainfall will have a better weightage as it affects the water flow directly and factors such as slope or TWI are much heavier since they can play a major role in water velocity/ accumulation. The reclassification of the layers into risk categories (low to high) is done in GIS software. These would create a complete risk map which shows the range of risk from very low to very high based on the combined influence of each factor. It produces a map of which parts of the catchment are more susceptible to intense water surges, aid in serving local authorities in resource risk management, and prescription safety planning. The map also acts as a bio monitor, with modifications to rainfall or land use resulting in periodic revision of the map so that future risk assessments remain valid.

According to the weightage analysis based on AHP evaluating water surge risks at Sungai Pandan Waterfall, rainfall is ranked as very high, followed by slope in high, LULC in medium and DEM and TWI as low and very low priorities to enter in model. Most importantly, rainfall as the most vital factor of water surge events given that there is an obvious correlation between significant precipitation and increased flow as well as surges which had gained a very high weightage. This is followed by assigning a large weight on slope since it controls the velocity as well as the direction of movement of water and steeper slopes result in greater runoff speed intensifying risks from surge. The medium weighting for land use /land cover is due to its systemic nature with respect to water accumulation in different zones and rearranging the natural drain direction. On the other hand, information extracted from digital elevation models (DEM), although somewhat important in terms of topography context, contributes less to surge events than rain and slope. Lastly, the topographic wetness index (TWI) is weighted as very low, meaning it can show where groundwater might pool over time but has a minor influence on quick water surge risk (Bernama, 2023). The CI from AHP is 0.988 while the the CR is 0.02.

Factors	TWI	DEM	SLOPE	LULC	RAINFALL	Weightage
TWI	1	1/7	1/6	1/5	1/8	0.022
DEM	7	1	1/6	5	1/7	0.163
SLOPE	6	6	1	5	1/7	0.245
LULC	5	1/5	1/5	1	3	0.198
RAINFALL	8	7	7	1/3	1	0.372

Table 1 The pair-wise comparison matrix, and final weights (w_i) for flood susceptibility criteria of Sungai Pandan Waterfall

Figure 19 presents a map that highlights the water surge risk zones, with colours indicating different levels of risk. Green represents very low-risk areas, which are typically flat or have high infiltration potential. Light green signifies low-risk zones, found on moderate slopes with manageable water accumulation. Yellow marks medium-risk areas, often characterized by moderate slopes and rainfall. Orange represents high-risk zones, indicating steep slopes or areas with significant water flow, while red highlights very high-risk regions, which are steepest, experience heavy rainfall, and have the highest potential for rapid water surges. The upstream section is categorized as high risk, while the midstream and downstream areas are identified as medium risk. The prevalence of yellow pixels on the map suggests that most of the study area falls into medium-risk zones.

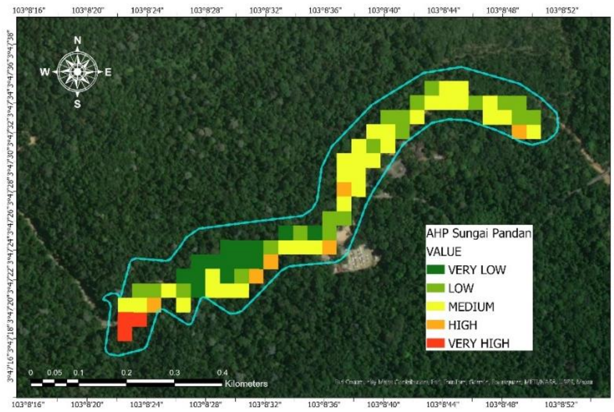

Figure 19. Water surge risk map of Sg. Pandan Waterfall

5. Conclusion

The study on water surge risk mapping at Sungai Pandan Waterfall highlights the critical need for updated and effective disaster management strategies in Malaysia, particularly in recreational areas prone to such natural disasters. Using geospatial technology and AHP the study has identified that Sg. Pandan Waterfall area is a medium-risk water surge zones due to combination of three main factors including terrain elevation, land use or rainfall pattern.

The results indicate that slope areas are particularly susceptible to the rapid water surges following heavy rainfall, and these can translate to dire consequences for tourists as well as the ecosystem nearby. In this way, this integrative risk mapping not only improves the process for allocating resources and preparing for disasters but also serves to educate about flood susceptibility, which is consistent with worldwide activities to develop more resilient communities. Consequently, this research points out for the necessity to modernize environmental monitoring and disaster preparedness introducing an efficacious water surges risk management based on technology implementation.

6. References

[1] Adnan N 2024 Sinar Harian: "Tragedi berkelah: Ibu maut, tiga anak hilang dihanyut kepala air". *https://www.sinarharian.com.my/article/648442/berita/semasa/tragedi-berkelah-ibu-maut-tiga-anak-hilang-dihanyut-kepala-air* Retrieved on 13 Aug 2024

[2] Ahmad A, Hashim UKM, Wahid RA, Sakidin H, Sufahani SF, Amin ARM, Abdullah MM and Quegan S 2019 Implementation of land cover change detection based on supervised classifications of multispectral satellite data for leveraging internet of things *ARPN Journal of Engineering and Applied Sciences* **14** (10) 1863-1870

[3] Ahmad F 2024 Utusan Malaysia: "60 terkandas di Kolam Puteri Air Terjun Gunung Ledang diselamatkan.", *https://www.utusan.com.my/berita/2024/09/60-terkandas-di-kolam-puteri-air-terjun-gunung-ledang-diselamatkan/* Retrieved on 16 Sept 2024

[4] Bernama 2023 "Hujan lebat luar biasa punca kepala air di Jeram Air Putih – Bomba" *https://www.astroawani.com/berita-malaysia/hujan-lebat-luar-biasa-punca-kepala-air-di-jeram-air-putih-bomba-426686* Retrieved on 20 Sept 2024

[5] Farhadi H and Najafzadeh M 2021 Flood risk mapping by remote sensing data and random forest technique *Water* **13**(21) 3115

[6] Hakim WL and Lee WC 2020 A review on remote sensing and GIS applications *Korean Journal of Remote Sensing* **36**(6-1) 1303-1322

[7] Hassan H 2018 "Profil Pahang 2018" *https://jpbd.pahang.gov.my/wp-content/uploads/2023/04/Profil-Pahang-2018.pdf* Retrieved on 15 Aug 2024

[8] Mansor HA 2022 Dewan Kosmik, "Mengurangkan Risiko Kepala Air". *https://dewankosmik.jendeladbp.my/2022/09/13/4130/* Retrieved on 04 Sept 2024

[9] Google Maps 2024. *https://www.google.com/maps/place/3%C2%B047'27.8%22N+103%C2%B008'40.7%22E/@3.*

7913159,103.1418277,16.5z/data=!4m12!1m7!3m6!1s0x31c8c86c1f93bc5b:0x32f8c1a35b097379!2sSungai+Pandan+Waterfall!8m2!3d3.7910325!4d103.1446271!16s%2Fg%2F11c3w8hk09!3m3!8m2!3d3.7910 Retrieved on 29 Aug 2024

[10] Marzuki Z 2024 Majoriti: "Kepala air Slim Village: 19 mangsa terperangkap selamat, 170 penduduk ditempatkan di 2 PPS". *https://majoriti.com.my/berita/2024/08/24/video-kepala-air-slim-village-19-mangsa-terperangkap-selamat-170-penduduk-ditempatkan-di-2-pps* Retrieved on 17 Aug 2024

[11] Mehebub S and Haroon S 2019 Vulnerability to storm surge flood using remote sensing and GIS techniques: A study on Sundarban Biosphere Reserve, India *Remote Sensing Applications: Society and Environment* **13** 106-120

[12] Moh HB 2012. National Disaster Management Agency (NADMA). *https://www.nadma.gov.my/bi/corporate/vision-mission* Retrieved on 12 Aug 2024

[13] Omdena 2021 flood risk assessment using analytical hierarchy process (AHP) and machine learning models, *https://www.omdena.com/blog/flood-risk-assessment-using-ahp-and-ml-togo* Retrieved on 19 Sept 2024

[14] Ramayah U 2024. Astro Awani: "25 individu terperangkap akibat kejadian kepala air." *https://www.astroawani.com/berita-malaysia/25-individu-terperangkap-akibat-kejadian-kepala-air-483040* Retrieved on 02 Sept 2024

[15] Rashid S 2024 Berita RTM: "Tiga disahkan maut tragedi kepala air di Lembah Maksina, Lahad Datu". *https://berita.rtm.gov.my/nasional/senarai-berita-nasional/senarai-artikel/tiga-disahkan-maut-tragedi-kepala-air-di-lembah-maksina-lahad-datu* Retrieved on 24 Aug 2024

[16] Samah AA 2022 Berita Awani: "Fenomena kepala air, penukaran guna tanah sebabkan kejadian". *https://www.facebook.com/watch/?v=979004539438651* Retrieved on 31 July 2024

[17] Selvam K 2023 Water surge - what you need to know. *https://www.sinardaily.my/article/200290/focus/national/water-surge---what-you-need-to-know#:~:text=%22Water%20surge%20is%20a%20phenomenon,any%20obstacle%2C%22%20he%20said* Retrieved on 28 July 2024

[18] Shamel 2019 Destinations: "Air Terjun yang anda wajib pergi di Malaysia". *https://www.tripjalan.com/destinations/air-terjun-yang-wajib-anda-pergi-di-dalam-malaysia/#:~:text=Tahukah%20anda%20di%20dalam%20Malaysia,air%20terjun%20tersorok%20didalam%20hutan* Retrieved on 23 Aug 2024

[19] Tan R 2023 Aonic: LiDAR scanning vs. traditional surveying: A comprehensive comparison: *https://blog.aonic.com/blogs-application/lidar-scanning-vs-traditional-surveying-a-comprehensive-comparison* Retrieved on 11 Sept 2024

[20] Wahid MH 2022. Bernama: "Bomba kenal pasti 186 kawasan risiko kepala air". *https://www.freemalaysiatoday.com/category/bahasa/tempatan/2022/09/27/bomba-kenal-pasti-186-kawasan-risiko-kepala-air/* Retrieved on 15 July 2024

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