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# Open-Source GIS Applications for Flood and Landslide Assessment: Comparative Cases from Poland and Malaysia

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**Abstract**: Research on natural disasters requires analytical procedures that are rapid, reproducible, and based on sound scientific principles. Such procedures should also be accessible to institutions responsible for environmental monitoring, land-use planning, and disaster risk reduction. This study evaluated the practical use of publicly available geospatial data and open-source GIS tools for the preliminary assessment of two contrasting natural hazards: the September 2024 flood in Lower Silesia, Poland, with particular focus on the urban floodplain of Wrocław, and the December 2022 landslide in Batang Kali, Selangor, Malaysia. The study utilised Copernicus Sentinel-2 MSI Level-2A satellite imagery, digital elevation model (DEM) data from the Copernicus programme, OpenStreetMap vector layers, and spatial processing in QGIS. The methodology employed a pre- and post-event change-detection approach based on spectral indices. The Normalized Difference Water Index (NDWI) was used to map the extent of flooding, while the Normalized Difference Vegetation Index (NDVI) was used to identify vegetation disturbances associated with the landslide. Raster classification, elevation analysis, vector-layer overlay, and thematic mapping were subsequently used to delineate disaster-affected areas and examine their spatial relationships with built-up areas, hydrographic features, and terrain morphology. The results show that the Copernicus Data Space Ecosystem and QGIS provide a transparent and cost-effective analytical environment for the preliminary assessment of natural disaster impacts. In the Wrocław case, the NDWI helped identify flooded areas and infrastructure potentially exposed to flooding. In the Batang Kali case, differences in NDVI helped identify patterns of vegetation disturbance associated with the landslide-affected area. The study demonstrates that open-source geospatial tools can support repeatable natural disaster analysis, geospatial education, and early-stage decision support for disaster risk reduction.

**Keywords:** Geographic Information Systems; Copernicus; QGIS; flood mapping; landslide analysis.

## 1.0 Introduction

Natural disasters increasingly require analytical methods that are clearly grounded in a spatial context and technically reproducible. Such methods must also be accessible to institutions responsible for natural disaster risk reduction, environmental monitoring, land-use planning, and emergency response (Smith et al., 2023). Floods and landslides are among the most destructive natural hazards. They result from complex interactions among atmospheric conditions, topography, land cover, hydrological processes, and human presence in vulnerable areas. Their impacts are rarely limited to the immediate physical extent of an event. Instead, they can affect infrastructure networks, urban areas, environmental systems, and the capacity of local authorities to maintain public safety. The analysis of natural disasters therefore cannot be limited to descriptive reporting. It requires the integration of geospatial data, remote sensing, topographic information, and spatial interpretation within a coherent analytical framework. Disaster risk arises from interactions between environmental processes and human activities. Factors such as extreme rainfall, changes in runoff conditions, urban expansion, and land-use change can increase the susceptibility and vulnerability of river valleys, floodplains, slopes, and suburban areas to natural hazards. The United Nations Office for Disaster Risk Reduction (UNDRR) emphasises that disaster impacts are becoming increasingly systemic, potentially triggering cascading effects across different sectors and regions (United Nations Office for Disaster Risk Reduction [UNDRR], 2022). In this context, spatial data analysis is not merely a technical operation but also an important component of risk management. It supports the identification of vulnerable areas, interpretation of hazard mechanisms, and disaster preparedness through evidence-based preventive measures.

Floods are among the major hydrological hazards in Europe, particularly in low-lying river valleys and densely developed urban areas. Their occurrence and severity are influenced by rainfall intensity, catchment response, river-channel capacity, floodplain morphology, and the spatial distribution of buildings and infrastructure. In Poland, flood risk remains a persistent concern, particularly in areas located along major river systems, including the Odra River basin. The September 2024 flood in southwestern Poland, including the Wrocław region, demonstrated the importance of rapid spatial assessment for urban flood-risk analysis. Events of this type require the delineation of flood-affected areas, identification of potentially affected buildings, and assessment of the relationship between inundation and terrain elevation. Previous studies of flood risk in Europe have emphasised that changing flood regimes and socio-economic vulnerability make spatially explicit, data-driven analysis essential for planning risk-reduction and adaptation measures (Kundzewicz, 2012).

Landslides constitute a distinct but equally serious category of natural hazard. Their occurrence is influenced by slope morphology, lithological and soil conditions, groundwater conditions and rainfall infiltration, vegetation cover, land-use pressure, and local engineering interventions. In tropical regions, heavy rainfall is one of the most important triggers of landslides, debris flows, and related slope failures. The catastrophic landslide at Batang Kali, Selangor, Malaysia, in December 2022 illustrates the destructive potential of rainfall-induced landslides in humid tropical environments. The event resulted in substantial loss of life and underscored the need for methods capable of identifying landslide-affected areas, interpreting terrain characteristics, and documenting spatial conditions before and after an event. Because field access to disaster sites can be difficult, hazardous, or delayed, remote sensing and GIS provide valuable and practical tools for preliminary assessment.

Geographic Information Systems (GIS) have become a key component of natural-hazard analysis and research. They enable the collection, management, processing, analysis, and visualisation of spatial information. GIS also facilitates the integration of raster and vector

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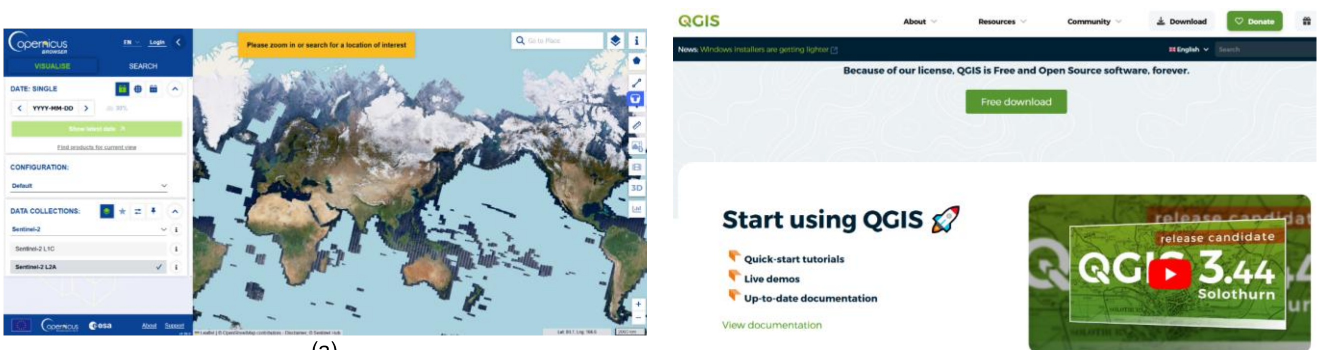
datasets, including satellite imagery, digital elevation models, hydrographic layers, road networks, building footprints, administrative boundaries, and land-cover data. This integrative capability is particularly important in disaster analysis, where the hazard itself, its environmental determinants, and its consequences for the built environment need to be considered collectively. The scientific foundations of GIS emphasise spatial relationships, scale, topology, data quality, and analytical reproducibility as important elements of geographic reasoning (Longley et al., 2015).

Satellite remote sensing further expands the analytical capabilities of GIS by providing repeatable, synoptic, and spatially continuous observations of the Earth's surface. Multispectral imagery is particularly useful for detecting environmental changes before and after extreme events. The comparison of pre- and post-event conditions represents a classical approach to digital change detection. Differences between observations acquired at different points in time can be used to identify changes in land cover, surface moisture, vegetation condition, and surface exposure (Singh, 1989). In natural-hazard research, this approach provides a useful basis for distinguishing event-related signals from pre-existing landscape conditions, provided that data quality, cloud cover, seasonality, and image-acquisition geometry are appropriately considered (Figure 1).

Spectral indices are among the most widely used tools in satellite-based environmental analysis. The Normalized Difference Water Index (NDWI) is widely used to distinguish open-water features and identify water-covered areas in remote sensing imagery (McFeeters, 1996). In flood analysis, NDWI can be used to delineate surface water and potentially inundated areas. Its application can be further supported by threshold classification, terrain interpretation, and vector-layer overlay. The Normalized Difference Vegetation Index (NDVI), originally developed for vegetation monitoring, remains one of the most widely used indicators of vegetation condition and land-cover disturbance (Rouse et al., 1974). In landslide analysis, changes in NDVI can provide an indirect indication of vegetation removal, exposed soil, deposition of landslide material, and disturbance along a landslide-affected area. However, NDVI-based interpretation of landslides should be treated with caution because changes in vegetation can also result from seasonality, weather conditions, agricultural activities, and other processes unrelated to landsliding, particularly in tropical environments.




(a) (b)

Figure 1: Overview of the Copernicus Browser (a) and QGIS (b) systems. Sources: Copernicus Data Space Ecosystem and QGIS.org (2026a).

(a) (b)

Figure 2: Relief and rescue operations in flood-stricken Wrocław (Poland, 2024) (a) and at the Batang Kali landslide site (Malaysia, 2022) (b). Photo sources: Global Empowerment Mission Europe (2024) and Malay Mail (2022).

The growing availability of open Earth observation data has transformed the practical aspects of natural disaster analysis. The Copernicus programme, particularly the Sentinel-2 multispectral satellite mission, provides a valuable data source for environmental monitoring, land-cover analysis, vegetation assessment, and inland water monitoring. The Copernicus Data Space Ecosystem and Copernicus Browser facilitate access to satellite imagery and support the search, visualisation, and download of relevant products for specific areas of interest. This

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accessibility is particularly important for research teams, public institutions, and educational projects that require transparent and cost-effective access to Earth observation data.

At the same time, QGIS (QGIS.org, 2026a) provides a mature, free, and open-source GIS environment for spatial analysis, raster processing, vector-layer overlay, map creation, and reproducible geospatial workflows. The combination of Copernicus data and QGIS therefore provides a technically accessible analytical environment for disaster risk research without requiring commercial GIS software.

Despite the widespread availability of GIS and satellite data, there remains a methodological need to demonstrate and evaluate how open geospatial workflows can be applied to different hazard types under diverse geographical and environmental conditions. Floods and landslides differ substantially in their spatial characteristics and remote-sensing responses. Floods generate relatively direct water-related spectral signals and are strongly influenced by low-lying terrain, drainage networks, and hydrological connectivity. Landslides, in contrast, often require indirect interpretation of vegetation disturbance, exposed soil, slope morphology, and the spatial patterns of slope failure determined by terrain characteristics. Consequently, a general remote-sensing and GIS framework needs to be adapted to the physical characteristics of each hazard process.

This study addresses this methodological need by presenting a comparative application of publicly available geospatial data and open-source GIS tools to two natural-disaster case studies: the September 2024 flood in Lower Silesia, Poland, with particular focus on the urban context and floodplains of Wrocław (Global Empowerment Mission Europe, 2024), and the December 2022 landslide in Batang Kali, Malaysia (Malay Mail, 2022). The analysis utilised Copernicus Sentinel-2 satellite imagery (e.g., Jensen, 2015), digital elevation model (DEM) data from the Copernicus programme, OpenStreetMap vector data, and spatial processing in QGIS. The methodological framework included the detection of pre- and post-event changes, flood mapping using the NDWI, NDVI-based detection of vegetation disturbances associated with the landslide, interpretation of terrain characteristics, and overlay analysis of vector layers representing selected infrastructure elements.

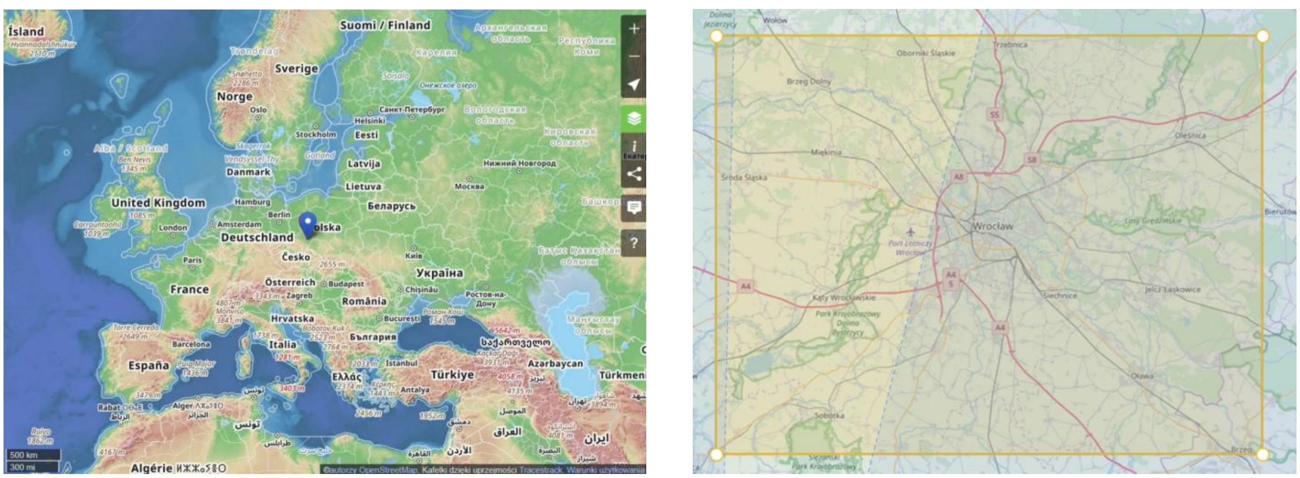
## 2.0 Study Area

The analysis was designed as a comparative geospatial study of two areas affected by natural disasters, representing different hazard mechanisms, climatic conditions, topography, and analytical requirements. The first study area is located in Wrocław, Lower Silesia, Poland, and was selected for analysis of the September 2024 flood along the Odra River. The second study area is located in Batang Kali, Selangor, Malaysia, and was selected to analyze the December 2022 landslide at Father's Organic Farm.

This dual-case-study structure allows for testing the open geospatial workflow under two fundamentally different environmental conditions: on a low-lying urban floodplain in Central Europe and on a tropical, forested slope in Southeast Asia. These two study areas were defined as the primary spatial basis, and the analysis specified the use of open-source satellite data, DEMs, and vector data for both locations.

### *2.1 Wrocław and Lower Silesia, Poland*

The area covered by the flood analysis is in the city of Wrocław, in the Lower Silesian Voivodeship in southwestern Poland (Fig. 3). Wrocław is situated in the Odra River valley, where the urban structure, floodplains, levees, canals, bridges, transportation infrastructure, and riverside areas form a complex hydrological and anthropogenic system.



(a) (b)

Figure 3: The geographical location of the city of Wrocław (a) and an example study area map (b). Sources: OpenStreetMap contributors and Tomiczek (2026).

For the purposes of a detailed GIS analysis, the area of interest (AOI) was limited to a compact urban-river section of Wrocław, roughly bounded by latitudes from 51.09525° N to 51.11121° N and longitudes from 17.04911° E to 17.06739° E. This area included the main river corridor, adjacent low-lying areas, built-up areas, and infrastructure elements relevant to the assessment of flood exposure. The selected scale was appropriate for creating maps based on Sentinel-2 data, overlaying vector layers in QGIS, and interpreting the effects of flooding on buildings and urban land cover. This area was designated as Lower_Silesia_flood_AOI and characterized as an urban and riverside area analyzed using Sentinel-2 data, DEM, and OpenStreetMap.

From the perspective of physical geography, the study area in Wrocław constitutes a lowland river valley environment, where flood risk depends on: river flow, floodplain morphology, local elevation differences, hydraulic connections, and the degree of urbanization. The relatively flat terrain favors the accumulation of water in depressions and riparian zones, and dense urbanization increases the potential impacts of even spatially limited flooding. Elevation values in the area of interest (AOI) range approximately from 113.5 m to 150 m above sea level. Areas below approximately 120 m above sea level were interpreted as particularly prone to flooding in the adopted DEM-based procedure.

The flood in September 2024 in southwestern Poland posed a serious hydrological threat to Wrocław and other parts of Lower Silesia. In response to the flood situation, the Polish government declared a state of natural disaster in parts of the Lower Silesian, Opole, and Silesian provinces. Reports at the time indicated that in the second half of September 2024, Wrocław was hit by a massive flood wave on the Oder River

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(Office of the Prime Minister, 2024). In the case of Wrocław, the study area was not selected as an abstract test site, but as a real urban environment at risk of flooding. The extent of the flooding, the low-lying terrain, the distribution of buildings, and the proximity of watercourses were spatially interrelated. This area was suitable for testing water detection based on the NDWI index, interpreting elevation data using a DEM model, and overlaying vector data from OpenStreetMap regarding buildings.

The study area map covered the area of interest (AOI) in Wrocław, including the Odra River, urbanized areas, major watercourses, and selected reference infrastructure. The map included: a coordinate grid, a north arrow, a scale, a legend, and a clearly defined border around the area of interest (AOI). The coordinate reference system (CRS) used was WGS 84 for geographic presentation and a projected coordinate reference system (CRS) for area calculations in the metric system.

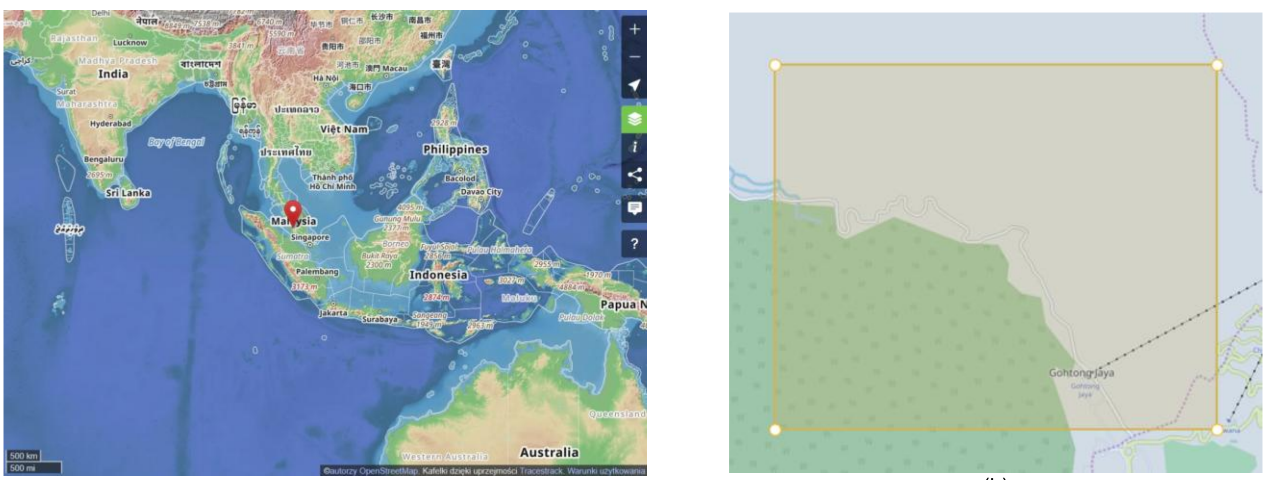
### *2.2 Batang Kali, Selangor, Malaysia*

The landslide study area is located along the Jalan Batang Kali–Genting Highlands road in the Hulu Selangor region of Malaysia (Figure 4), between the towns of Batang Kali and Gohtong Jaya, at the Father's Organic Farm campsite. The site is located approximately 50 km north of Kuala Lumpur and lies within a tropical environment characterised by steep slopes, dense vegetation, heavy rainfall, and strong interactions between slope conditions and surface and subsurface water. The Batang Kali site was affected by a major landslide on a steep, forested slope, with the failure extending towards lower-lying areas containing built-up and agricultural land.

The Batang Kali disaster occurred on 16 December 2022. An official report published on a website dedicated to documenting the event and commemorating its victims states that 92 people were involved in the incident, of whom 61 were rescued and 31 lost their lives. The report attributed the disaster primarily to a natural slope failure influenced by rainfall and geological conditions. A report by the Associated Press based on the declassified government investigation likewise stated that the landslide resulted in 31 deaths, including 13 children. Prolonged heavy rainfall in the days preceding the disaster was identified as an important contributing factor (Associated Press, 2023). The Batang Kali landslide therefore represents a significant case of rainfall-induced slope failure with implications extending beyond the geomorphological process itself. The event has important implications for land-use planning, slope management, visitor safety, and emergency preparedness, particularly in tropical environments.

From a geomorphological perspective, the Batang Kali area differs substantially from the floodplain environment of Wrocław. It comprises steep and densely vegetated slopes where slope instability is influenced by several interacting factors, including:

- slope gradient,
- properties of regolith and soil,
- groundwater conditions,
- disturbance of the vegetation cover,
- dynamics of soil flow.




(a) (b)

Figure 4: The geographical location of Batang Kali (a) and an example study area map (b). Sources: OpenStreetMap contributors.

The source materials describe the landslide as a sequence of events comprising an initial slope failure, a temporary accumulation of landslide material, and a subsequent debris-flow phase that affected the lower sectors of the campsite.

The estimated volume of displaced material was approximately 450,000 m³. The extent of the landslide was determined through the interpretation of geospatial data. These conditions provide a suitable basis for detecting vegetation disturbance using NDVI, interpreting slope morphology using a digital elevation model (DEM), and spatially delineating the initiation, transport, and deposition zones of the landslide.

The tropical environmental conditions have direct methodological implications. Frequent cloud cover, rapid vegetation regrowth, high humidity, and complex terrain can limit the interpretability of optical satellite imagery. These limitations are particularly relevant to post-event analysis based on Sentinel-2 imagery.

Under such conditions, changes in vegetation cover can be detected by analysing changes in NDVI. However, landslide boundaries should be interpreted in conjunction with terrain morphology, visible evidence of exposed soil, field observations or information from official reports, and other relevant spatial data. This is one reason why the Batang Kali case is methodologically informative. It demonstrates both the potential and the limitations of open-source optical remote sensing for the assessment of landslides in tropical environments.

The maps prepared for the Batang Kali study area included the area of interest (AOI) surrounding Father's Organic Farm, the approximate landslide source area, the sediment transport route, the deposition zone, the nearby road corridor, and the local topographic context. Each map included a coordinate grid, north arrow, scale bar, and legend, and clearly distinguished the interpreted landslide-affected area from the surrounding forested terrain.

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*2.3 General Qualitative Comparison of Research Areas*

Taken as a whole, the two study areas provided a deliberately contrasting basis for methodological comparison. Wrocław represented a lowland urban environment vulnerable to river flooding. The primary subject of the spectral analysis was surface water, with the Normalized Difference Water Index (NDWI) serving as the principal analytical indicator.

Batang Kali, in contrast, represented a tropical hillside environment in which the main visible post-event features were vegetation disturbance and exposed soil. Accordingly, changes in the Normalized Difference Vegetation Index (NDVI) were considered more appropriate for identifying vegetation disturbance than direct water-index mapping. The contrast between the two cases supported the main objective of the analysis: to assess whether publicly available data from the Copernicus programme and QGIS-based processing workflows can provide a reproducible and scientifically interpretable basis for the preliminary assessment of natural disaster impacts across different hazard types and geographical conditions.

## 3.0 Materials and Methodology

*3.1 Materials*

The analysis utilised an integrated set of publicly available geospatial datasets, including satellite imagery, digital elevation models, and vector data. These datasets supported the comparative analysis of two different types of natural hazards. The analysis was conducted in two study areas: Lower Silesia, Poland, representing the 2024 flood, and Batang Kali, Malaysia, representing the 2022 landslide. The locations of both study areas are presented in the previous section of the article.

The primary data source was satellite imagery from the Copernicus programme, specifically Sentinel-2 MultiSpectral Instrument (MSI) Level-2A data. These data provide multispectral observations at spatial resolutions of up to 10 m, enabling detailed characterisation of the Earth's surface. Sentinel-2 data were selected because of their wide availability, systematic acquisition, and suitability for monitoring environmental changes. Images acquired before and after the respective events were used to support change detection and identify event-related changes in surface conditions (see Table 1 for an overview of the datasets and tools used).

For the Wrocław flood case, the pre-event Sentinel-2 image was acquired on 24 August 2024, while the post-event image was acquired on 18 September 2024. For the Batang Kali landslide case, the primary pre-event Sentinel-2 image used during workflow development was acquired on 7 July 2022, while the post-event image was acquired on 9 March 2023. An additional image acquired on 22 December 2010 was used solely as a historical reference for contextual interpretation.

Based on the Sentinel-2 imagery, the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) were calculated. NDVI was used to assess vegetation condition and identify areas exhibiting vegetation disturbance, whereas NDWI was used to identify surface-water features and delineate potentially flooded areas. These indices provided complementary measures of surface conditions and supported the identification of changes associated with the respective extreme events.

Table 1: Datasets and analytical tools used in the study

| No. | Material or tool | Source | Spatial role in the study | Main application |
|---|---|---|---|---|
| 1. | Sentinel-2 MSI Level-2A imagery | Copernicus Data Space Ecosystem | Multispectral raster data | NDWI, NDVI, pre-event and post-event change detection |
| 2. | Copernicus DEM | Copernicus Data Space Ecosystem | Elevation raster data | Terrain elevation, slope context, geomorphological interpretation |
| 3. | Building, road, and hydrographic vectors | OpenStreetMap contributors | Vector exposure data | Overlay with hazard masks and infrastructure interpretation |
| 4. | QGIS 3.40 | QGIS.org (2026a) | GIS analytical environment | Raster processing, vector analysis, classification, cartography |
| 5. | Google Earth Engine | Gorelick et al. (2017) | Cloud geospatial processing environment | Satellite data screening, index calculation, workflow verification |

Table 2: Characteristics of the analyzed study areas

| No. | Study area | Location | Type of disaster | Year of event | Main analytical methods |
|---|---|---|---|---|---|
| 1 | Wrocław / Lower Silesia | Poland (Central Poland) | Flood | 2024 | NDWI, GIS spatial analysis, elevation analysis |
| 2 | Batang Kali / Selangor | Malaysia (Southeast Asia) | Landslide | 2022 | NDVI, pre-event/post-event difference analysis, GIS surface analysis |

To account for topographic conditions, the Copernicus DEM was used to analyse terrain elevation and slope. These data are particularly important for identifying areas potentially susceptible to flooding and mass-movement processes. For the flood analysis, the DEM was used to identify low-lying areas, whereas for the landslide analysis, it was used to identify steep slopes that may be more susceptible to destabilisation.

An additional source of information was vector data obtained from the OpenStreetMap database, including infrastructure features such as buildings and road networks. These data were used to assess the potential impacts of the analysed hazards on the built environment, particularly by identifying infrastructure located within potentially affected areas. Integrating the vector data with the remote-sensing results enabled more detailed spatial analysis and assessment of potentially exposed infrastructure.

Data processing and spatial analysis were conducted using two main analytical platforms. Google Earth Engine (GEE) (Gorelick et al., 2017) was used to process satellite datasets and calculate spectral indices, while QGIS (version 3.40) was used to visualise the results, conduct spatial analyses, and prepare thematic maps. The use of open-source tools enabled the overall workflow to be implemented in a straightforward, repeatable, and reproducible manner, facilitating its application to other study areas.

To clearly define the locations of the study areas and facilitate their spatial traceability, the geographic characteristics of the selected areas are summarised in Table 2. This information provides a consistent spatial reference for the study areas and facilitates future comparisons with analyses conducted under similar environmental conditions.

*3.2 Methodology / Framework / Theory*

The methodology used in this study combines observational data obtained from satellite platforms with spatial analysis to provide a comprehensive assessment of the impacts of selected natural hazards. The approach is designed to be repeatable and adaptable, allowing it to be applied to different types of environmental hazards while accounting for their specific characteristics and geographical contexts.

The research process was divided into several main stages:

- Data acquisition.
- Pre-processing.
- Calculation of spectral indices.
- Analysis of temporal changes.
- Classification of hazard-affected areas.
- Spatial analysis.
- Visualisation of results.

The methodological framework was developed as a structured process for detecting geospatial changes before and after a disaster event. This approach is widely used in remote sensing because it enables the identification of spatial changes through comparisons of imagery acquired before and after an event (Singh, 1989). In this study, the approach was adapted to two different natural-hazard processes. The Wrocław flood in Lower Silesia (2024) was treated as a problem of direct water detection, in which the spectral response of surface water constituted the primary diagnostic feature. The Batang Kali landslide (2022), in contrast, was treated as a problem of indirect disturbance detection, in which vegetation loss, exposed soil, and terrain characteristics served as indicators of mass movement.

(1) Definition of the area of interest and spatial standardisation

- The first methodological step involved defining the area of interest (AOI) and establishing spatial standardisation. In both cases, the AOI was digitised or imported as a polygon layer and subsequently verified using satellite imagery and reference basemaps.
- The Wrocław AOI covered the urban and riverine areas along the Oder River, whereas the Batang Kali AOI encompassed the landslide initiation zone, the main movement path, and the deposition area near Father's Organic Farm. All datasets were initially checked using the WGS 84 geographic coordinate reference system.
- For metric area calculations and spatial overlay operations, the datasets were transformed into appropriate projected coordinate reference systems. This step was essential because incorrect handling of coordinate reference systems can introduce spatial offsets between raster and vector layers, particularly when integrating satellite imagery, DEM data, and OpenStreetMap features.

(2) Selection and pre-processing of satellite data

- The second stage involved the selection and pre-processing of satellite imagery. Sentinel-2 Level-2A images were selected based on acquisition date, coverage of the area of interest (AOI), cloud cover, and suitability for visual interpretation. The relevant spectral bands were imported into QGIS and clipped to the AOI. The raster layers were checked for cell size, spatial extent, alignment, and NoData values.
- Where necessary, the rasters were resampled to a common 10-m grid before the spectral indices were calculated. Pixels affected by clouds were interpreted with caution, and areas containing visible cloud or cloud-shadow contamination were excluded from quantitative interpretation where such contamination could affect the results. This consideration was particularly important for the tropical Batang Kali case, where persistent cloud cover represents a significant limitation for optical remote sensing.

(3) Calculation of spectral indices

- The third step involved calculating the spectral indices. The Normalized Difference Vegetation Index (NDVI) was calculated as follows (Equation 1):

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (1)$$

- For Sentinel-2, the near-infrared (NIR) band corresponds to Band B08, while the red band corresponds to Band B04. NDVI was used primarily to analyse vegetation disturbance associated with the Batang Kali landslide and, to a lesser extent, to characterise the land-cover context of the Wrocław flood area.

- High NDVI values generally indicate dense and healthy vegetation, whereas low or substantially reduced values may indicate exposed soil, disturbed vegetation, built-up surfaces, water, or debris. The NDVI concept originates from early research on vegetation remote sensing and remains a fundamental indicator for assessing vegetation condition (Rouse et al., 1974).

- The Normalized Difference Water Index (NDWI) was calculated following McFeeters (1996) as follows (Equation 2):

$$NDWI = \frac{Green - NIR}{Green + NIR} \quad (2)$$

- For the Sentinel-2 satellite, the green band corresponds to channel B03, and the NIR band corresponds to channel B08. The NDWI index was used as the primary indicator for creating flood maps in Wrocław because it highlights open water features while minimizing the influence of vegetation and dry soil.
- This approach is based on the theoretical foundations proposed by McFeeters (1996), who introduced the NDWI index to identify areas of open water in remote-sensing images. In this analysis, the NDWI index was calculated separately for images taken before the event and for those taken during the event.

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(4) Temporal change detection and determination of index thresholds

- The fourth stage involved analysing temporal changes and determining classification thresholds. For the flood analysis, pre-event and event-period NDWI rasters were compared to identify areas exhibiting an increase in the surface-water signal.
- A binary water mask was generated using an NDWI threshold of 0.05. This threshold was selected through visual comparison with Sentinel-2 true-colour and false-colour imagery, the mapped hydrographic network, low-lying areas identified from the DEM, and expert interpretation in QGIS. Because no independent field-based validation data were available, the resulting flood mask was treated as a preliminary classification rather than as a definitive inventory of flooded areas.
- Pixels with NDWI values equal to or greater than 0.05 were classified as water or potentially flooded areas, whereas pixels with values below this threshold were classified as non-water.
- Permanent water bodies were identified using the pre-event water mask, while newly detected water features or areas exhibiting increased water signals were assessed using the event-period mask and the differential NDWI layer. This procedure was intended to distinguish flood-related water expansion from pre-existing river channels and permanent water bodies.
- For the landslide analysis, the principal diagnostic layer was the NDVI difference layer (Equation 3):

$$\Delta NDVI = NDVI_{post} - NDVI_{pre} \qquad (3)$$

- Negative ΔNDVI values were interpreted as potential indicators of vegetation loss or land-cover disturbance. For the final landslide-related disturbance mask, a conservative threshold of $\Delta NDVI \leq -0.20$ was applied. The resulting areas were then visually assessed using post-event Sentinel-2 imagery, terrain morphology, elevation, visible patterns of exposed soil, and the documented location of the Batang Kali landslide. The interpretation was not based solely on NDVI because tropical vegetation can regenerate rapidly, while reductions in NDVI may also result from cloud contamination, seasonal changes, agricultural activity, or other land-cover changes unrelated to landsliding.

(5) Refinement of classified results

- The fifth stage involved refining the classified results. Binary raster masks were cleaned to reduce isolated pixels and minor spatial artefacts. Noise reduction involved raster filtering, application of a minimum mapping unit criterion, and visual inspection.
- The refined raster masks were subsequently converted into vector polygons to facilitate area calculations and spatial-overlay analysis.
- The polygon boundaries were verified against the original Sentinel-2 imagery, terrain characteristics derived from the DEM, and relevant contextual layers. This verification was necessary to minimise potential misinterpretation associated with mixed pixels, cloud-contaminated areas, urban shadows, and spectrally ambiguous surfaces.

(6) Integration of hazard maps with topographic and infrastructure data

- The sixth stage involved integrating hazard maps with topographic and infrastructure datasets.
- For Wrocław, building footprints, road networks, and hydrographic features obtained from OpenStreetMap were overlaid on the classified flood map. This enabled the identification of buildings located within or near potentially flooded areas and facilitated interpretation of the spatial relationships among flooding, proximity to the river, and low-lying terrain.
- For Batang Kali, the vegetation-disturbance mask was interpreted together with terrain slope and elevation to distinguish the approximate landslide source area, transport corridor, and deposition zone. The interpreted landslide extent was also compared with available visual documentation of the event.

(7) Map preparation and documentation

- The final methodological stage involved preparing the maps and documenting the results. The final maps were produced in QGIS and included:
    - the boundaries of the area of interest (AOI);
    - classified hazard-affected areas;
    - an appropriate basemap or satellite imagery;
    - scale bar;
    - north arrow;
    - coordinate information;
    - legend;
    - information on data sources.
- The maps were designed not only as illustrative outputs but also as visual analytical products supporting the interpretation of the spatial patterns identified through the workflow (Figure 5).

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$$\boldsymbol{Pre-event\ vs\ Post-event}$$
$$\downarrow$$
$$[\boldsymbol{CHANGE\ DETECTION}]$$
$$\boldsymbol{\Delta NDVI\ /\ \Delta NDWI}$$
$$\downarrow$$
$$[\boldsymbol{THRESHOLDING}\ \&\ \boldsymbol{CLASSIFICATION}]$$
$$\boldsymbol{Binary\ classification\ (0/1)}$$
$$\downarrow$$
$$[\boldsymbol{SPATIAL\ ANALYSIS}]$$
$$\boldsymbol{Overlay\ with\ buildings\ (OSM)}$$
$$+\ \boldsymbol{DEM\ analysis\ (slope, elevation)}$$
$$\downarrow$$
$$[\boldsymbol{RESULTS}]$$
$$\boldsymbol{Flood\ extent\ /\ Landslide\ area}$$
$$+\ \boldsymbol{Risk\ zones}$$
$$\downarrow$$
$$[\boldsymbol{VISUALIZATION}]$$
$$\boldsymbol{Maps\ (QGIS)}$$

Figure 5: General methodological framework used for both case studies. The workflow includes data acquisition from Copernicus and OpenStreetMap, pre-processing in QGIS and/or Google Earth Engine, spectral index calculation, pre- and post-event change detection, binary classification, DEM-supported interpretation, vector-layer overlay, map preparation, and final spatial interpretation.

The adopted methodology should be regarded as a geospatial assessment approach rather than a substitute for hydrodynamic modelling, geotechnical slope-stability analysis, or detailed field surveys. Its main advantage lies in the rapid, transparent, and reproducible identification of areas affected by natural hazards using publicly available data and tools.

This approach is particularly relevant to education, preliminary planning, and early-stage disaster risk reduction, especially in contexts where access to commercial software or proprietary high-resolution data is limited. It should be emphasised that the methodology was developed based on project materials produced by students under the supervision of their academic advisors, together with our own analyses. The resulting framework provides a coherent and comprehensive approach to the use of geospatial data for natural-hazard assessment.

## 4.0 Results

### *4.1 Flood Mapping Results for the Wrocław Study Area*

The flood analysis for the Wrocław study area provided a spatial representation of water-covered areas and areas potentially affected by flooding within the selected urban–riverine study area. The use of Sentinel-2 MSI Level-2A imagery enabled comparison of surface conditions before and during the event. The QGIS-based workflow allowed the integration of spectral analysis results with elevation data and infrastructure-related vector data. The main outcome of this stage was the generation of a binary water and flood mask based on the Normalized Difference Water Index (NDWI), calculated using the green and near-infrared bands of Sentinel-2 (Figure 6).

The NDWI raster for the study period showed a clear concentration of positive values associated with surface water along the Odra River corridor and in selected adjacent low-lying areas. Binary classification using an NDWI threshold of 0.05 separated pixels interpreted as water bodies or water-affected areas from non-water land-cover classes. The resulting mask broadly reflected the main hydrographic structure of the area of interest (AOI) and identified several localised zones with spectral responses consistent with surface water or flood-related moisture. The strongest water-related signatures occurred in the immediate vicinity of the river channel, secondary water bodies, and low-lying parts of the floodplain. Even within a relatively small and urbanised AOI, Sentinel-2 data supported the detection of spatial patterns associated with flooding, particularly when interpreted in conjunction with topography and land-use context.

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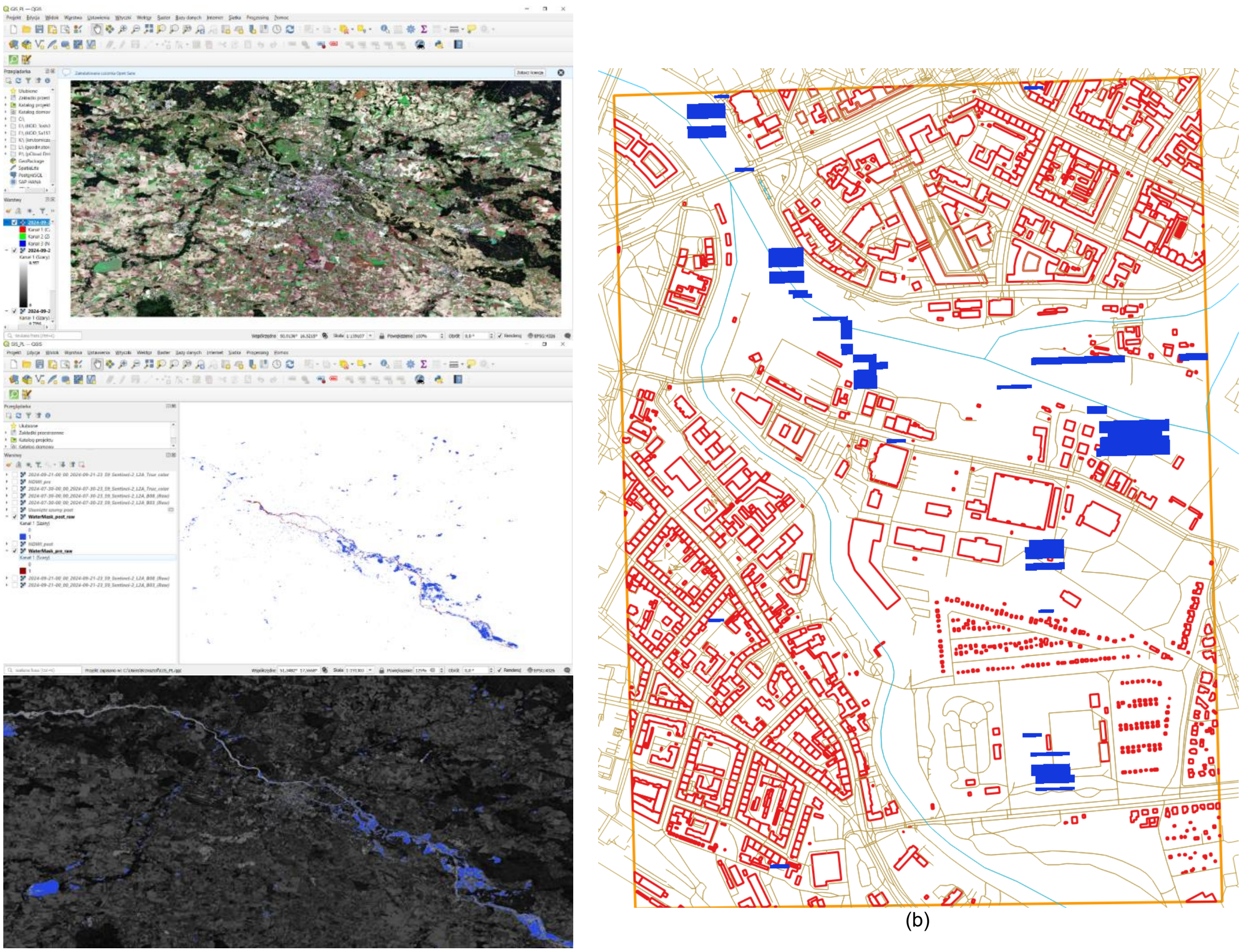

(a) (b)

Figure 6: Location of the study area in Wrocław / Lower Silesia, Poland, used for flood analysis (1) and identification of potentially flood-exposed buildings (2). Sentinel-2/OpenStreetMap/QGIS workflow.

A pre-event image acquired on 24 August 2024 served as a reference for distinguishing permanent water bodies from areas where an increased water signal was observed during the flood. The event-period image, acquired on 18 September 2024, showed increased cloud cover, which limited the reliability of spectral interpretation in some parts of the area of interest (AOI). Nevertheless, the image retained sufficient information for preliminary mapping of water-covered areas following spatial cropping, visual quality control, and interpretation in QGIS. Differences between pre-event and event-period NDWI values indicated increased surface-water signals in selected parts of the floodplain and riparian zones. These areas were interpreted as potentially flood-affected areas, as their locations corresponded to the river corridor and areas of relatively low terrain elevation.

An analysis of terrain elevation based on the Copernicus DEM provided an independent topographic reference for interpreting the NDWI classification. Elevations within the study area ranged from approximately 113.5 to 150 m above sea level. The lowest terrain was concentrated around river sections and floodplain areas. Areas below approximately 120 m above sea level showed greater potential for water accumulation. Overlaying the NDWI-derived mask with the DEM showed that the identified water-related pixels were not randomly distributed. The previously reported area of approximately 70 km² was excluded from the present analysis because it referred to an earlier, larger exploratory AOI and was therefore not directly comparable with the compact, coordinate-defined AOI used for the Wrocław case in this study. Accordingly, the final interpretation focuses on the localised water-affected areas within the defined AOI.

The analysis also demonstrated the value of combining raster classification with vector data representing potentially exposed infrastructure. Building footprints from OpenStreetMap were clipped to the AOI and overlaid on the water and flood mask. A total of 1,388 buildings were identified within the study area. A relatively high concentration of potentially exposed buildings occurred along the river corridor and in selected central, northern, eastern, and southeastern parts of the AOI, where residential, industrial, and warehouse buildings are located near low-lying areas. This analysis should not be interpreted as a definitive assessment of building damage. Rather, it represents a spatial identification of buildings located within or near the delineated flood-affected areas, indicating locations where more detailed verification, field inspection, or higher-resolution data would be required.

The distribution of potentially flood-exposed buildings further demonstrates that flood-impact assessment cannot be limited to delineating the spatial extent of inundation alone. Integrating flood-related change detection with topographic and infrastructure data provides additional information on the potential spatial consequences of flooding within urban areas.

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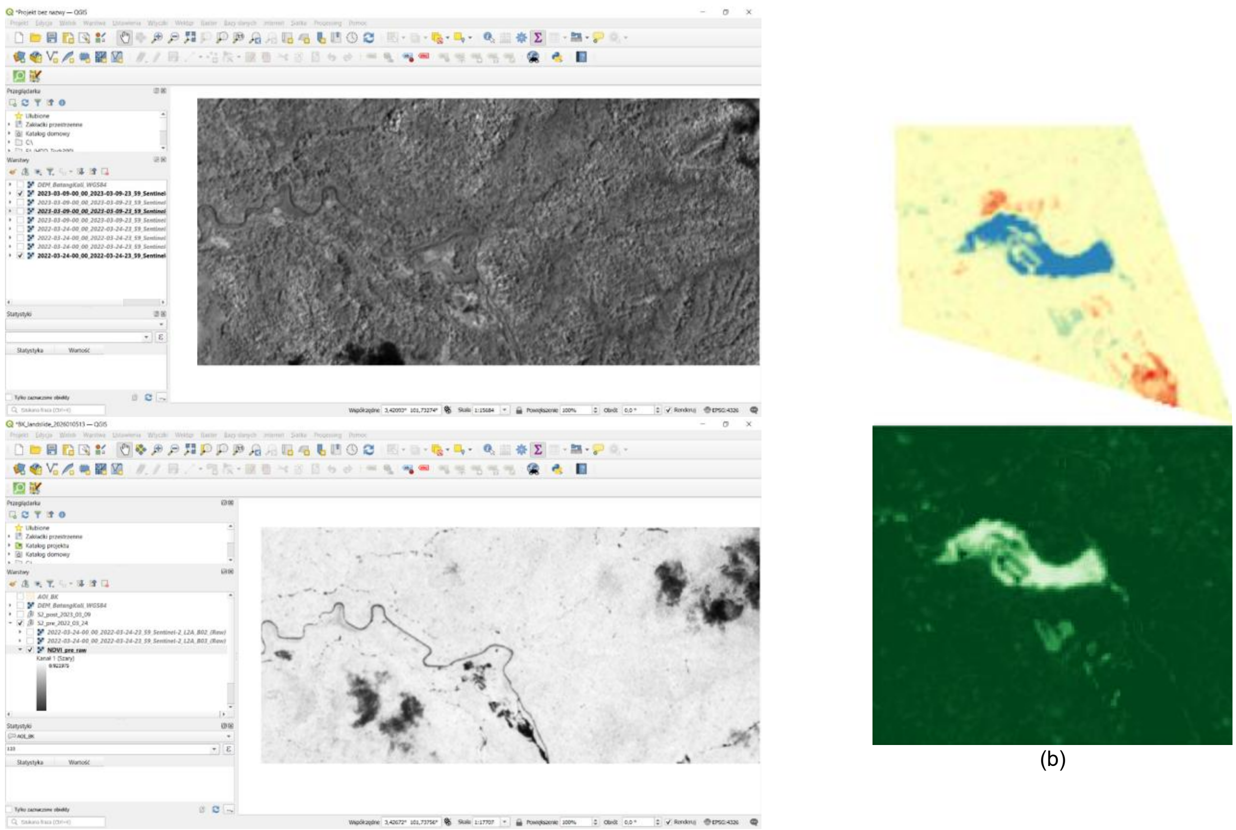
In an urban environment, the value of a flood map depends on how effectively it can be related to built-up areas, transportation corridors, land use, and local topography. The Wrocław case demonstrated that a relatively simple workflow based on the NDWI, combined with DEM and OpenStreetMap layers, can provide a useful first-order assessment of potentially affected urban areas. The main outcome was therefore not only the identification of water-covered pixels, but also the demonstration of how open-source tools such as Copernicus data and QGIS can integrate flood detection with a spatial assessment of potentially exposed urban features.

*4.2 Landslide Mapping Results for the Batang Kali Study Area*

The analysis of the Batang Kali area enabled a spatial interpretation of the zone affected by the landslide. The analysis was based primarily on changes in NDVI, terrain characteristics, and comparison with the documented location of the disaster site at Father's Organic Farm. Unlike the Wrocław flood case, where the phenomenon mapped was more directly associated with the presence of surface water, the landslide case required indirect interpretation. The principal remote-sensing indicator was the reduction in vegetation condition and continuity following the slope failure, expressed as negative values in the differential NDVI layer.

The NDVI comparison revealed a distinct zone of vegetation disturbance along the interpreted landslide corridor. This zone contrasted with the surrounding forested areas, which retained higher NDVI values and relatively continuous vegetation cover. The negative NDVI anomaly spatially corresponded to areas showing a transition from dense vegetation to exposed soil, ground surfaces, and disturbed substrate. The observed spatial pattern was consistent with the expected spectral response of a soil or debris-flow path associated with a landslide in a tropical, forested environment. Under such conditions, slope failure can remove or bury vegetation and expose mineral soil or other underlying surface materials.



(a) (b)

Figure 7: Location of the Batang Kali-Selangor study area used for landslide analysis (a) and an example of the landslide disturbance mask generated from ΔNDVI threshold classification (b).

The landslide-affected area, estimated from the analysis of Sentinel-2 data, was approximately 1.24 km². This estimate was obtained by comparing the pre-event reference image acquired on 7 July 2022 with the post-event image acquired on 9 March 2023, using a conservative ΔNDVI threshold of $\leqslant -0.20$ to identify disturbed vegetation. This value should be treated as an estimate of the visibly disturbed surface area within the selected AOI rather than as a definitive measurement derived from engineering surveys. Under tropical conditions, the result may be influenced by image acquisition date, cloud cover, vegetation regrowth, spatial resolution, and the threshold used to distinguish disturbed from relatively undisturbed areas.

In tropical environments, vegetation can regenerate rapidly, potentially reducing the detectability of the original landslide boundary in imagery acquired several weeks or months after an event. The mapped extent should therefore be interpreted as a cautious geospatial estimate of visible surface disturbance within the selected AOI.

Analysis of the DEM indicated that the landslide occurred on steep, forested terrain, where elevation differences and slope geometry influenced the downslope movement of landslide material. The available data indicate an elevation change from approximately 150 m in the upper part of the affected slope to approximately 113.5 m in the lower area where material accumulated. The spatial distribution of the NDVI anomaly generally followed the downslope direction, extending from the interpreted initiation area towards the deposition zone (Figure 7). This spatial correspondence provides supporting evidence that the vegetation disturbance was associated with the documented landslide corridor rather than representing an isolated spectral anomaly. However, the NDVI analysis alone cannot establish the dynamics or mechanics of the landslide.

The landslide mechanism, as interpreted from the available geospatial data and supporting documentation, was consistent with a sequence involving initial slope failure followed by downslope movement and subsequent debris-flow development affecting the lower parts of the campsite. The estimated total volume of displaced material was approximately 450,000 m³, while the initial landslide volume was estimated at approximately 47,000 m³. These values suggest that the final scale of the event was influenced by processes such as material entrainment, sediment accumulation, and secondary flow transformation. From a GIS perspective, the mapped extent of the event therefore encompassed not only the initial failure area but also the associated transport and deposition zones.

Although NDWI played a secondary role in the Batang Kali analysis, it provided additional information on water- or moisture-related surface conditions within the landslide corridor. An NDWI threshold of 0.05 was applied in accordance with the flood-analysis procedure; however, its interpretation differed in the landslide case. NDWI was not used to delineate flooding as the primary hazard. Instead, it was used to identify moisture-related surface features that may be associated with saturated soils, local drainage, or water-affected ground surfaces. This interpretation should remain cautious because optical spectral indices cannot directly determine pore-water pressure, subsurface saturation, or geotechnical strength parameters (Bandira et al., 2024).

The Batang Kali results demonstrate that publicly available satellite imagery and QGIS can support the identification of landslide-affected areas in forested environments following a disaster event. At the same time, the results indicate that landslide mapping is inherently more interpretive than flood mapping. Changes in NDVI can identify surface manifestations of the event, particularly vegetation loss and exposed soil, but cannot directly measure landslide depth or subsurface geotechnical characteristics, including the geometry of the internal slip surface, soil properties, rainfall infiltration, or slope-stability conditions. The mapped landslide extent should therefore be regarded as a geospatial interpretation rather than a definitive geotechnical assessment. Further verification would require field observations, higher-resolution imagery, engineering-geological data, and relevant precipitation information.

### *4.3 Comparative Results of the Two Case Studies*

A comparative analysis showed that the same open-data GIS workflow can be applied to different natural hazards, provided that the interpretation is adapted to the physical mechanisms of each process. In Wrocław, NDWI was the principal indicator because the analysis focused on surface-water detection. In Batang Kali, changes in NDVI were more informative because vegetation and land-cover disturbances associated with the landslide, rather than surface water itself, provided the main observable indicators.

The two cases also differed in the role of topography. In Wrocław, terrain elevation helped identify low-lying areas near the river corridor that were potentially more susceptible to water accumulation. In Batang Kali, terrain morphology provided important contextual information for interpreting the landslide initiation area, downslope movement, and deposition zone. These differences demonstrate that DEM-derived information is useful for both types of hazards, although its analytical significance depends on the physical characteristics of the process being investigated.

The comparison also showed that QGIS plays an important role in transforming remote-sensing results into interpretable geospatial products. The Copernicus system provided the primary satellite and elevation datasets, while QGIS supported raster cropping, spectral-index calculation, binary classification, vector-layer overlay, area calculation, and final cartographic preparation. As a result, the workflow remained transparent and reproducible without relying on commercial GIS software. This is particularly relevant to disaster risk reduction education and preliminary hazard assessment, especially in contexts where commercial software is unavailable or its acquisition is not cost-effective.

The quality and interpretability of the results were constrained by the limitations of optical satellite imagery. In Wrocław, cloud cover during the event period reduced the reliability of interpretation in some parts of the area of interest (AOI). In Batang Kali, tropical cloud cover, vegetation regrowth, and complex terrain increased uncertainty in delineating the landslide-affected area. These limitations do not invalidate the workflow; rather, they define its appropriate scope of application. The method is suitable for preliminary mapping, comparative analysis, educational training, and early-stage spatial interpretation. However, it should not be considered a substitute for hydrodynamic modelling, detailed geotechnical investigations, or official damage assessments.

## 5.0 Discussion

The results demonstrate that publicly available satellite data and open-source GIS software can provide a scientifically grounded basis for the preliminary assessment of natural disaster impacts. The two case studies differ in terms of hazard mechanisms, environmental conditions, spectral characteristics, and interpretation requirements. Both demonstrate that a structured workflow based on Copernicus Sentinel-2 satellite imagery, digital elevation model (DEM) data, OpenStreetMap vector data, and QGIS processing can support the identification of disaster-affected areas and the assessment of their spatial relationships with topography and infrastructure. This finding is particularly relevant to disaster risk reduction, where rapid, repeatable, and cost-effective spatial information may be required before detailed field surveys or specialised engineering analyses become available.

The Wrocław flood case demonstrates the practical value of NDWI-based mapping for identifying surface-water features and potentially flood-affected areas. The theoretical basis for this approach is consistent with McFeeters (1996), who demonstrated that NDWI enhances open-water features by contrasting the responses in the green and near-infrared portions of the spectrum. In this analysis, the NDWI-based water mask broadly reflected the main hydrographic structure of the area of interest (AOI) and identified additional water-covered areas near the Odra River corridor. This demonstrates that spectral-index analysis can support not only regional flood mapping but also assessment of relatively small urban–riverine areas, provided that the results are interpreted in conjunction with local topography, pre-event conditions, and land-use patterns.

At the same time, the Wrocław results demonstrate that flood mapping in urban environments is more complex than simply extracting water features from satellite imagery. Built-up surfaces, shadows, narrow channels, wet roofs, roads, and mixed pixels can produce ambiguous spectral responses. NDWI should therefore not be interpreted in isolation. In the present AOI, integrating NDWI classification with the Copernicus DEM and OpenStreetMap data provided additional spatial context for interpreting the results. The DEM helped assess whether water-related pixels were located in relatively low-lying areas, while the vector data enabled the flood mask to be related to potentially exposed infrastructure. The scientific value of flood mapping therefore depends not only on the spectral index itself but also on the quality and context of its integration within a broader GIS framework.

The Batang Kali landslide required a different interpretive approach. The phenomenon was not represented by a direct spectral target such as open water, but by indirect surface manifestations of mass movement. The principal diagnostic indicator was a decrease in NDVI associated with vegetation removal, soil exposure, sediment deposition, and disturbance of the slope surface. This interpretation is consistent with the established use of NDVI as an indicator of vegetation condition and surface disturbance (Rouse et al., 1974). In forested tropical

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environments, a marked decrease in NDVI following a landslide can provide a useful preliminary indicator of disturbance, particularly where access to the affected terrain is limited or hazardous.

However, landslide detection using NDVI requires greater caution than flood detection using NDWI. A decrease in NDVI may reflect vegetation loss associated with a landslide, but it may also result from cloud shadows, image-acquisition conditions, seasonal vegetation variability, agricultural clearing, deforestation, or rapid post-event vegetation regrowth. This consideration is particularly important in tropical environments such as Malaysia, where persistent cloud cover and rapid vegetation regrowth can obscure the original boundaries of a landslide. Consequently, the Batang Kali interpretation cannot rely solely on a differential raster. NDVI anomalies should instead be considered alongside geomorphological and geotechnical context, terrain characteristics derived from the DEM, the documented event location, slope direction, and available information on the landslide mechanism. This supports a broader methodological principle: spectral indices should be treated as diagnostic layers rather than definitive interpretations and should be evaluated within a process-based analytical framework.

The comparative results are consistent with the established principle that change detection is most informative when the observed spectral change has a clear physical relationship with the process under investigation (Singh, 1989). In the flood case, the relationship between surface-water presence and the NDWI response is relatively direct. In the landslide case, the relationship is more indirect, involving surface disturbance and associated vegetation loss expressed through changes in NDVI. Thus, NDVI primarily detects the land-cover effects of a landslide rather than the landslide mechanism itself. This distinction helps explain why flood mapping produced a more direct spatial signal, whereas landslide mapping required greater contextual and expert interpretation.


(a)


(b)

Figure 8: General views of areas affected by natural disasters: the city of Wrocław and the Batang Kali region. Photo sources: TOK FM/PAP (2024; permission required for publication) and Zackhaikaltarmizi (2022; CC BY-SA 4.0).

A universal GIS workflow should not be confused with a universal classification rule. The workflow may be general, but the choice of indicator, threshold-setting strategy, and validation approach must be tailored to the physical characteristics of the hazard process.

DEM data played an important role in both case studies, although their analytical significance differed between the two settings. In Wrocław, terrain elevation helped identify low-lying areas with greater potential for water accumulation and provided important topographic context for interpreting the flood-related water signals. In Batang Kali, terrain morphology provided a basis for interpreting slope instability, downslope sediment transport, and deposition. This demonstrates that elevation and slope-gradient data should be treated as important interpretive layers in disaster analysis rather than merely as supplementary information. In flood studies, DEM data can support the identification of low-lying areas and the interpretation of drainage and water-accumulation patterns. In landslide studies, DEMs provide a geomorphological framework for interpreting potential initiation, transport, and deposition zones. The integration of terrain data with spectral indices is therefore an important component of the analytical framework.

The analysis also demonstrated the operational value of QGIS as a central analytical environment. QGIS enabled the harmonisation of coordinate reference systems, raster clipping, calculation of spectral indices, binary classification, conversion of rasters to vector layers, spatial overlay, area calculation, and cartographic layout preparation. These functions are important because disaster analysis requires not only calculations based on remote-sensing data but also spatial interpretation through the integration of multiple datasets. QGIS also supports reproducibility, as the analytical workflow can be documented, repeated, modified, and applied to other study areas. Its open-source nature also avoids the licensing costs associated with commercial GIS software (QGIS.org, 2026b).

The Copernicus programme played an equally important role. Sentinel-2 provides multispectral observations with bands suitable for calculating NDVI and NDWI, while the Copernicus data infrastructure facilitates access to systematically acquired Earth observation products (Copernicus Data Space Ecosystem; European Space Agency). In this study, Copernicus data provided the primary satellite and elevation datasets for both case studies, while QGIS was used to process, integrate, visualise, and prepare these data as interpretable spatial products. The combination of Copernicus data and QGIS is therefore not only technically accessible but also methodologically relevant, as it enables transparent, cost-effective, and reproducible analysis of natural-hazard impacts.

The limitations of this study should also be clearly recognised:

- Optical-image limitations. Sentinel-2 optical imagery is sensitive to cloud cover, cloud shadows, haze, and atmospheric conditions. These limitations can be particularly important in tropical environments and may also affect image interpretation in urban areas.
- Spatial-resolution limitations. The spatial resolution of Sentinel-2 is adequate for many regional and landscape-scale analyses but may be insufficient for precise assessment at the scale of individual buildings, narrow channels, small pathways, or minor landslides.
- Threshold-classification limitations. Threshold-based classification is inherently simplified. A single NDWI or NDVI threshold may not perform consistently across different land-cover classes, illumination conditions, soil types, vegetation types, and urban environments.
- OpenStreetMap data limitations. OpenStreetMap provides valuable and widely available spatial data, but its completeness, positional accuracy, and level of detail may vary between locations and individual feature types.

These limitations do not diminish the value of the proposed methodology; rather, they define its appropriate practical and scientific scope. The method should be regarded as a preliminary geospatial screening approach suitable for rapid interpretation, educational applications, preliminary hazard mapping, and early-stage spatial decision support. It should not be considered a substitute for hydrodynamic modelling, hydraulic simulation, geotechnical slope-stability analysis, high-resolution photogrammetry, LiDAR surveys, or official damage assessments.

For flood applications, future comprehensive studies could incorporate Sentinel-1 SAR imagery, hydrological observations, water-level measurements, hydraulic modelling, and additional terrain and infrastructure data to improve the interpretation of flood extent, depth, and dynamics. For landslide applications, future studies should incorporate rainfall data, engineering-geological profiles, soil and material properties, geotechnical slope-stability analyses, and higher-resolution imagery. These additional datasets would support more detailed assessment of landslide initiation and progression and could improve estimates of the volume and spatial distribution of displaced material.

Despite these limitations, the analysis provides a useful methodological contribution. It demonstrates how open geospatial workflows can bridge the gap between satellite observations and the practical interpretation of natural-hazard events. The Wrocław case illustrates how NDWI, DEM data, and building footprints can be integrated to support the assessment of potentially flood-exposed urban areas, while the Batang Kali case demonstrates how changes in NDVI, combined with terrain interpretation, can help identify areas affected by landslides in a tropical environment.

The results also demonstrate that disaster analysis should be multi-layered, process-oriented, and grounded in geographic context. The proposed approach is therefore useful not only as a technical workflow but also as a teaching and research framework for developing geospatial competencies, including among students, in the field of Disaster Risk Reduction (DRR).

## 6.0 Conclusions

The study demonstrated that publicly available geospatial data and open-source GIS tools can provide a transparent, reproducible, and accessible basis for the preliminary assessment of natural-hazard impacts. The two case studies, namely the September 2024 flood in the Wrocław region of Lower Silesia, Poland, and the December 2022 landslide in Batang Kali, Selangor, Malaysia, were characterised by different hazard mechanisms, environmental conditions, and analytical challenges. Despite these differences, both cases demonstrated that a structured workflow based on Copernicus Sentinel-2 satellite imagery, DEM data from the Copernicus programme, OpenStreetMap vector layers, and spatial processing in QGIS can support the identification and interpretation of areas affected by natural hazards.

The flood analysis demonstrated the usefulness of the NDWI for detecting surface-water features and potentially flood-affected areas in an urban–riverine environment. When combined with elevation data and building footprints, the NDWI-based flood mask provided more than a simple representation of surface-water extent. It also supported a spatial assessment of potentially exposed areas by identifying buildings and infrastructure located within or near the delineated flood-affected areas. The Wrocław case therefore demonstrated that open geospatial workflows could support rapid preliminary analysis of urban flooding, particularly when spectral information, terrain characteristics, and vector data are interpreted together.

The analysis of the Batang Kali landslide demonstrated that changes in NDVI can provide a useful preliminary indicator of vegetation disturbance associated with mass-movement processes. This approach enabled the identification of areas where vegetation removal, exposed debris, and disturbed soil were spatially consistent with the interpreted landslide corridor. The case also demonstrated that NDVI-based interpretation requires greater contextual and geomorphological caution than flood mapping based on surface-water detection. In tropical environments, cloud cover, rapid vegetation regrowth, and complex land-cover conditions can reduce the reliability of the interpretation. Therefore, NDVI-derived disturbance should be evaluated in conjunction with topographic information, event documentation, and, where available, higher-resolution imagery and independent reference data.

The main conclusion of the analysis is that Copernicus data and QGIS provide a technically accessible and scientifically useful environment for preliminary natural-hazard assessment and spatial interpretation. Copernicus provides openly available Earth observation data, while QGIS supports data integration, spatial analysis, raster and vector processing, and cartographic visualisation. This combination is particularly relevant to universities, research teams, local authorities, and educational projects that require transparent and reproducible workflows without relying on commercial GIS software.

The proposed approach should primarily be regarded as a preliminary geospatial screening method. It does not replace hydrodynamic modelling, engineering-geological investigations, geotechnical slope-stability analysis, LiDAR-based mapping, or detailed official damage assessments.

The main advantages of the proposed methodological approach include rapid implementation, methodological transparency, low-cost data and software requirements, and adaptability to different regions and hazard types.

For detailed follow-up studies, the analytical framework could be expanded to incorporate Sentinel-1 SAR data, higher-resolution optical imagery, precipitation data, hydrological observations, and field-based geotechnical information. These additional datasets could improve the spatial interpretation and validation of the identified hazard-affected areas and provide greater insight into the physical processes underlying the observed changes.

In summary, the analysis demonstrated that open geospatial methods can support preliminary natural-hazard impact assessment, spatial planning, environmental monitoring, and disaster risk reduction. The workflow developed for the Wrocław and Batang Kali case studies provides a basis for application to other flood- and landslide-prone areas. However, such applications should be accompanied by appropriate adaptation to local terrain conditions, data availability and quality, image-acquisition characteristics, and the physical mechanisms of the hazards under investigation.

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**Conflicts of Interest:** The authors declare that there are no conflicts of interest in this study.

**Data Availability Statement:** The Sentinel source data are publicly available through the Copernicus program and Google Earth Engine. Derived rasters, validation tables, and project documentation used in this study are retained in the Silesian University of Technology-Universiti Utara Malaysia PBL project archive and are available from the corresponding author on reasonable request.

**Author Contributions:** Conceptualisation, methodology, investigation, data curation, formal analysis, visualisation, and writing – original draft preparation were contributed by the relevant members of the research team. Writing – review and editing, supervision, and project administration

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were undertaken by the senior members of the research team. All authors contributed to the interpretation of the results, critically reviewed the manuscript, and approved the final version

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