

Spatial analysis of LULC change and DEM-derived hydrological characteristics in a tropical micro-watershed (Lubuk Yu, Malaysia)

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ABSTRACT

Land use and land cover (LULC) change plays important role in influencing hydrological characteristics, especially in watersheds that are sensitive to both natural variability and anthropogenic disturbance. This study focuses on spatiotemporal LULC dynamics and examines terrain-derived hydrological characteristics in the Lubuk Yu watershed, Pahang, Malaysia (4.12 km²), using Geographic Information Systems (GIS) and remote sensing techniques. Multi-temporal Landsat 8 Operational Land Imager (OLI) imagery from 2016 and 2023 was classified using a supervised maximum likelihood approach into three dominant land cover classes: vegetation, water bodies, and barren land. The results indicate that vegetation cover decreased from 3.10 km² (75%) in 2016 to 2.80 km² (68%) in 2023, while water bodies increased from 0.78 km² (19%) to 1.01 km² (24%), and barren land increased from 0.24 km² (6%) to 0.29 km² (7%). Classification accuracy achieved 86.67% (Kappa = 0.77) for 2016 and 83.33% (Kappa = 0.74) for 2023, indicating substantial agreement with reference data. Hydrological characteristics derived from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) include watershed delineation, flow direction, flow accumulation, and stream ordering. Morphometric analysis indicates a drainage density of 28.64 km km⁻² and stream frequency of 29.78 streams km⁻², reflecting a dense and responsive headwater drainage system dominated by first-order streams (62 channels) with a total stream length of 68.34 km. Spatial overlay analysis reveals that areas experiencing vegetation reduction are frequently associated with zones of higher flow accumulation, particularly along tributary corridors, suggesting increased potential for runoff concentration. This study provides a process-oriented interpretation of how moderate land-cover changes in a tropical micro-watershed can be linked to terrain-controlled hydrological behaviour. The findings offer baseline insights to support watershed management, land-use planning, and environmental monitoring in Lubuk Yu and similar tropical catchments.

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1. INTRODUCTION

Land use dynamics and hydrological processes are closely interconnected and play a fundamental role in environmental sustainability and watershed management. Land Use and Land Cover (LULC) patterns control the spatial distribution of vegetation, water bodies, and exposed or developed surfaces, thereby influencing key hydrological processes such as surface runoff, infiltration, evapotranspiration, and soil erosion. Anthropogenic land-use changes, including deforestation, agricultural expansion, and localised development, can disrupt natural landscape

functions and alter hydrological equilibrium, leading to increased runoff, sediment transport, and potential water-quality degradation (Mohd Amin et al., 2014; Zeshan et al., 2021). In tropical regions such as Malaysia, characterised by high rainfall intensity and sensitive ecosystems, these impacts are often amplified, posing challenges to ecological stability and water resource sustainability (Kemarau et al., 2024; Mohd Amin et al., 2025).

The Lubuk Yu watershed in Pahang, Malaysia, is a small tropical catchment where interactions between land-cover transformation and hydrological processes are

particularly significant. The watershed comprises forested uplands, river networks, and areas of agricultural activity that provide ecological services and support local livelihoods. In recent years, the area has experienced gradual land use transitions associated with agricultural expansion, localised development, and selective vegetation clearing. Even moderate changes in land cover can influence hydrological behaviour by reducing infiltration capacity, increasing surface runoff, and altering sediment transport processes (Jarocińska et al., 2023). As a key hydrological corridor, Sungai Lubuk Yu may be particularly sensitive to changes in surrounding land cover, which can affect flow pathways, channel stability, and sediment dynamics.

Despite its ecological importance, the spatial relationship between recent LULC changes and terrain-controlled hydrological processes in the Lubuk Yu watershed remains insufficiently documented. Existing studies in Malaysia often address land use mapping and hydrological analysis separately, with limited integration of multi-source geospatial datasets for process-oriented interpretation. As a result, there is still limited understanding of how land cover transitions interact with terrain characteristics to influence drainage pathways, runoff concentration zones, and stream network development at the micro-watershed scale. Furthermore, the application of high-resolution UAV data to support or validate satellite-based land cover interpretation in such settings remains limited.

Advances in Geographic Information Systems (GIS) and remote sensing techniques provide an effective framework to address these gaps. Multi-temporal satellite imagery enables the detection of land cover changes over time, while Digital Elevation Models (DEMs) allow the extraction of terrain-derived hydrological parameters such as flow direction, flow accumulation, watershed boundaries, and stream hierarchy. When combined with UAV observations, these datasets can enhance spatial interpretation, particularly in spectrally complex or heterogeneous environments.

Accordingly, this study aims to evaluate the relationship between land-cover dynamics and hydrological characteristics in the Lubuk Yu watershed using an integrated geospatial approach. The study addresses three key questions: (i) what major LULC changes occurred between 2016 and 2023; (ii) how are these changes spatially associated with DEM-derived hydrological characteristics such as flow accumulation, drainage structure, and runoff concentration pathways; and (iii) how can Landsat, DEM, and UAV observations be integrated to improve interpretation of watershed condition in a tropical micro-watershed?

This research utilises Landsat 8 imagery (2016 and 2023), SRTM DEM data, and UAV observations to analyse

land use dynamics and terrain-driven hydrological characteristics. The main contribution of the study lies in examining the sensitivity of a small tropical watershed to recent land-cover changes by linking classified LULC patterns with DEM-derived indicators of runoff concentration and drainage organisation. Rather than emphasising novelty in data integration, the study adopts a process-oriented spatial interpretation at the micro-watershed scale, supported by morphometric indices and UAV-assisted validation. The findings provide baseline insights for watershed management, conservation planning, and sustainable land-use decision-making in tropical catchments.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted in the Lubuk Yu watershed in Pahang, Malaysia, a region characterised by strong interactions between land-use dynamics and hydrological processes. These interactions influence watershed stability, surface runoff behaviour, and river system responses under tropical climatic conditions (Kemarau et al., 2025).

The watershed exhibits a heterogeneous landscape comprising forested areas, agricultural land, exposed surfaces, and riverine systems. This spatial variability, combined with pronounced topographic gradients, provides suitable conditions for analysing the relationship between land cover changes and hydrological characteristics. Similar tropical catchments in Malaysia have demonstrated a strong sensitivity of runoff response to land-surface modifications (Wan et al., 2025).

As shown in Figure 1, the Lubuk Yu watershed is centred at approximately 3.7531° N and 102.6525° E, covering an area of about 4.13 km². The basin is defined by undulating terrain with varying slope gradients that control surface runoff pathways and drainage organisation. Elevation ranges from lowland river valleys to surrounding upland areas, forming a typical tropical micro-watershed system with well-defined headwater channels.

The region experiences a humid tropical climate characterised by high rainfall intensity and seasonal variability, which plays a dominant role in driving hydrological processes such as runoff generation, infiltration, and sediment transport (Jabatan Alam Sekitar, 2022). The watershed is primarily underlain by tropical forest soils and alluvial deposits along riverbanks, influencing infiltration capacity and erosion susceptibility.

These combined characteristics make the Lubuk Yu watershed a representative tropical micro-catchment for examining the interaction between land cover change and terrain-driven hydrological response. The site is particularly

well-suited for assessing how moderate land use modifications influence runoff concentration, drainage structures, and watershed dynamics over the period from 2016 to 2023.



Figure 1: Location map of the Lubuk Yu River Basin.

2.2. Data collection and sources

This study utilised an integrated set of primary and secondary geospatial datasets to ensure the reliability and analytical robustness of the spatial assessment. The primary datasets consisted of multi-temporal satellite imagery, Digital Elevation Model (DEM) data, and high-resolution Unmanned Aerial Vehicle (UAV) imagery. Secondary datasets included administrative boundary layers and reference data used for classification validation and spatial consistency checks. The integration of these datasets enabled a comprehensive evaluation of spatiotemporal land use and land cover (LULC) dynamics and DEM-derived hydrological characteristics within the Lubuk Yu watershed.

Multi-temporal Landsat 8 Operational Land Imager (OLI) imagery for 2016 and 2023 was obtained from the United States Geological Survey (USGS) EarthExplorer platform. The Landsat datasets have a spatial resolution of 30 m, which is appropriate for detecting landscape-scale variations in vegetation, water bodies, and exposed or non-vegetated surfaces. To minimise atmospheric and cloud-related interference, images with less than 10% cloud cover were selected. A Colour Infrared (CIR) band combination (Band 5 – Near Infrared, Band 4 – Red, and Band 3 – Green) was applied to enhance vegetation reflectance and improve the separability of land cover classes, particularly between vegetated and non-vegetated surfaces (Ji et al., 2025).

Topographical and hydrological characteristics were derived from the Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global DEM, which provides elevation data at approximately 30 m spatial resolution. The DEM dataset was obtained from the USGS database in GeoTIFF format

(Gonçalves et al., 2019). Before analysis, the DEM was projected to a consistent coordinate reference system to ensure spatial compatibility with Landsat imagery. The DEM was subsequently used to derive terrain attributes and hydrological parameters, including elevation, slope, flow direction, flow accumulation, drainage networks, and watershed boundaries (Khalid et al., 2021).

To complement medium-resolution satellite observations and support interpretation in spectrally complex areas, high-resolution UAV imagery was acquired in 2025 using an unmanned aerial platform equipped with an RGB camera. The UAV survey was conducted under favourable atmospheric conditions to minimise shadow and illumination effects. The resulting imagery provided a detailed visualisation of riverbanks, narrow drainage channels, vegetation patterns, and exposed soil surfaces that are not fully resolved in Landsat imagery. Although the UAV data were not used as a primary classification dataset, they served as supplementary reference data to validate land cover interpretation and enhance confidence in areas with spectral ambiguity (Kemarau et al., 2025).

The UAV imagery was imported into ArcGIS 10.8 and georeferenced using ground control references derived from existing spatial layers and basemap imagery. This ensured spatial alignment with Landsat and DEM datasets within a unified GIS environment. The integrated datasets were subsequently used for classification validation and interpretation of hydrological features within the study area.

All spatial data processing and analysis were conducted using ArcGIS version 10.8, which supports raster processing, vector analysis, hydrological modelling, and cartographic visualisation. Land cover statistics and percentage changes were calculated using Microsoft Excel, while documentation and graphical outputs were prepared using Microsoft Word and Microsoft PowerPoint. All thematic maps were produced using a consistent cartographic framework in the WGS 84 coordinate system, incorporating scale bars, north arrows, and standardised legends to ensure spatial accuracy and interpretability.

2.3 Image preprocessing, LULC classification, DEM processing, and hydrological analysis

This section describes the analytical framework used to assess land-use dynamics and DEM-derived hydrological characteristics in the Lubuk Yu watershed. The methodology integrates remote sensing processing, GIS-based spatial analysis, and terrain-derived hydrological modelling. The workflow was structured into four sequential stages: (i) image preprocessing, (ii) land use and land cover (LULC) classification, (iii) DEM processing, and (iv) hydrological

analysis.

Image preprocessing was performed to ensure spectral consistency and comparability between multi-temporal Landsat datasets (2016 and 2023). Radiometric and atmospheric corrections were applied to minimise sensor and atmospheric distortions. Cloud masking was conducted to remove cloud-contaminated pixels, while band compositing using a Colour Infrared (CIR) combination (Band 5 – Near Infrared, Band 4 – Red, and Band 3 – Green) was applied to enhance vegetation reflectance and improve class separability.

LULC classification was performed using a supervised maximum likelihood algorithm. This method is widely applied in tropical watershed studies due to its effectiveness in discriminating spectrally heterogeneous land cover classes. Training samples were selected based on spectral characteristics and supported by UAV imagery and high-resolution basemap data to improve classification reliability. The classification scheme was simplified to three dominant classes (vegetation, water bodies, and barren land) to align with the 30 m spatial resolution of Landsat imagery and to capture general hydrological response patterns rather than detailed land-use inventories. Classification accuracy was evaluated using confusion matrices and kappa statistics, providing a quantitative assessment of classification performance (Ji et al., 2025; Kemarau et al., 2025).

DEM processing was conducted using the Shuttle Radar Topography Mission (SRTM) 30 m dataset. Preprocessing steps included sink filling to remove artificial depressions and projection alignment to ensure spatial compatibility with Landsat-derived outputs. The processed DEM was used to derive key terrain attributes, including elevation, slope, flow direction, and flow accumulation. These parameters form the basis for delineating drainage networks and watershed boundaries.

Hydrological analysis was performed using DEM-derived flow modelling techniques. Stream networks were extracted based on flow accumulation thresholds, and stream ordering was determined using the Strahler method. In addition to descriptive spatial outputs, morphometric indices were calculated to provide quantitative insight into drainage organisation and hydrological response characteristics of the watershed. These indices include drainage density (total stream length per unit area) and stream frequency (number of streams per unit area), which are commonly used to infer runoff potential, drainage efficiency, and watershed responsiveness (Khalid et al., 2021; Ping et al., 2024).

To strengthen the linkage between land cover dynamics and hydrological behaviour, a spatial overlay analysis was performed between LULC changes and flow

accumulation patterns. This approach enables identification of areas where vegetation reduction coincides with zones of concentrated runoff, providing a spatially explicit interpretation of potential hydrological impact within the micro-watershed.

2.3.1 Image preprocessing

Image preprocessing was conducted to ensure spectral consistency, spatial accuracy, and suitability of the Landsat datasets for subsequent classification and spatial analysis. Multi-temporal Landsat 8 Operational Land Imager (OLI) images from 2016 and 2023 were processed in a GIS environment to produce standardised multiband raster datasets for analysis.

Initially, individual spectral bands were combined into a multiband composite to enable simultaneous analysis of visible and near-infrared reflectance properties. A Colour Infrared (CIR) band combination (Band 5 – Near Infrared, Band 4 – Red, and Band 3 – Green) was applied to enhance vegetation reflectance and improve discrimination between vegetated and non-vegetated surfaces. In this configuration, healthy vegetation appears in red tones. At the same time, water bodies and exposed or built-up surfaces are represented by darker or neutral tones, facilitating clearer visual interpretation and supporting classification accuracy (Ji et al., 2025).

To ensure spatial consistency and relevance to the study area, the satellite imagery was clipped using a predefined boundary of the Lubuk Yu watershed. The boundary was delineated using hydrological and administrative references to represent the catchment's extent accurately. This masking process removed pixels outside the study area, reducing data redundancy and ensuring that subsequent analyses were confined to the watershed extent (Khalid et al., 2021).

The resulting pre-processed multiband datasets were then used as the primary input for supervised LULC classification. This preprocessing step ensured that the imagery was radiometrically consistent, spatially aligned, and optimised for reliable land cover discrimination and hydrological interpretation (Kemarau et al., 2025).

2.3.2 Land Use and Land Cover (LULC) classification

Land use and land cover (LULC) classification was conducted to quantify spatial and temporal changes within the Lubuk Yu watershed between 2016 and 2023. A supervised classification approach based on the Maximum Likelihood Classification (MLC) algorithm was adopted due to its established effectiveness with multispectral data and its statistical robustness for distinguishing land cover types in heterogeneous tropical environments.

The classification scheme was defined using three

dominant land cover classes: vegetation, water bodies, and barren land. This simplified classification was intentionally adopted to align with the spatial resolution of Landsat 8 imagery (30 m) and to ensure reliable spectral separability between classes. At this resolution, smaller or heterogeneous features such as dispersed settlements, narrow transport corridors, recreational infrastructure, and fragmented agricultural plots often exhibit mixed spectral responses. They cannot be consistently distinguished as separate classes. These features were therefore aggregated within the barren land category, representing non-vegetated and sparsely vegetated surfaces. This classification framework is applied consistently throughout the manuscript and is appropriate for capturing general land-surface conditions relevant to hydrological interpretation rather than for detailed land-use inventory mapping.

Training samples for each class were generated by manually digitising representative polygons across the study area. Sample selection was guided by spectral characteristics observed in the Colour Infrared (CIR) composite (Band 5–4–3), where vegetation exhibits strong reflectance in the near-infrared band, water bodies appear spectrally dark, and non-vegetated surfaces display relatively higher reflectance in visible bands. Additional support from UAV imagery and high-resolution basemap data improved the reliability of training sample selection, particularly in areas with spectral ambiguity.

Spectral statistics derived from the training samples were used to generate class signatures for the MLC process. The algorithm assigns each pixel to the class with the highest probability based on the statistical distribution of spectral values within each class. This probabilistic approach ensures that classification reflects the inherent variability of spectral responses across the landscape. The resulting classified maps represent the spatial distribution of vegetation, water bodies, and barren land within the Lubuk Yu watershed.

Post-classification processing was conducted to refine classification outputs and enable quantitative analysis. The classified raster datasets were converted into vector format to facilitate spatial analysis and area calculation. The extent of each land cover class was computed in hectares and expressed as percentage coverage relative to the total watershed area. These values were compared between 2016 and 2023 to quantify the magnitude and direction of land cover changes. The resulting statistics provide a basis for interpreting landscape transformation and its potential influence on watershed hydrological processes.

2.3.3 Hydrological analysis using DEM

Hydrological analysis was conducted to characterise terrain-controlled runoff pathways and drainage organisation

within the Lubuk Yu watershed using Digital Elevation Model (DEM) data. The analysis utilised the Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global DEM with a spatial resolution of approximately 30 m, which is suitable for watershed-scale hydrological assessment.

Before analysis, the DEM was projected into a consistent coordinate reference system to ensure spatial compatibility with Landsat-derived datasets. Preprocessing included sink filling to remove spurious depressions that may disrupt continuous flow routing and introduce artefacts into the hydrological network.

Flow direction was derived using the deterministic eight-direction (D8) algorithm, which assigns each grid cell a flow path toward the neighbouring cell with the steepest downslope gradient. This approach provides a simplified representation of surface runoff routing across the terrain and forms the basis for subsequent hydrological modelling. The resulting flow direction raster encodes directional movement of water across the landscape and enables identification of dominant drainage pathways. A schematic representation of the D8 flow direction coding scheme used in this analysis is illustrated in Figure 2.

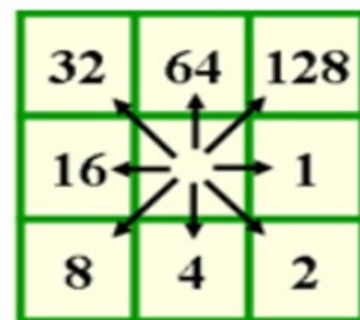


Figure 2: Schematic representation of D8 flow direction coding used to derive surface runoff pathways from DEM data.

Flow accumulation was subsequently computed to quantify the number of upstream cells contributing to each grid cell. Areas with high flow accumulation represent zones of runoff concentration and are typically associated with channel initiation and stream development. A threshold value for flow accumulation was applied to extract the drainage network, enabling the delineation of stream channels across the watershed. The selected threshold was determined based on visual calibration of channel initiation patterns to ensure a realistic representation of the drainage network.

Watershed delineation was performed by defining a pour point at the main outlet of the Lubuk Yu basin and tracing all upstream contributing cells based on the flow direction dataset. This process defines the hydrologically consistent boundary of the watershed and ensures that all analysed grid cells contribute runoff to a common outlet.

The extracted drainage network was further

analysed using the Strahler stream ordering method to characterise the hierarchical structure of the river system. In addition to the spatial representation of drainage patterns, morphometric indices were calculated to provide a quantitative description of watershed characteristics. These include drainage density (total stream length per unit area) and stream frequency (number of stream segments per unit area), which are commonly used to infer drainage efficiency, runoff potential, and watershed responsiveness.

Although the DEM-based analysis does not directly simulate hydrological variables such as discharge or sediment transport, it provides a spatially explicit framework for interpreting runoff concentration, drainage organisation, and terrain-driven flow processes. When integrated with LULC classification results, these hydrological indicators enable assessment of how land cover changes may influence surface runoff behaviour and watershed dynamics within the Lubuk Yu micro-watershed.

2.4 Data analysis and validation

Data analysis was conducted to quantify land use and land cover (LULC) changes and to evaluate the reliability of classification results and DEM-derived hydrological outputs. The analysis integrates statistical evaluation, spatial overlay techniques, and validation procedures to ensure robust results.

To assess classification accuracy, 90 validation points were generated using stratified random sampling to ensure proportional representation of vegetation, water bodies, and barren land classes. Reference data were derived from ground observations, high-resolution basemap imagery, and UAV images acquired in 2025. Validation focused particularly on river corridors and exposed surfaces, where spectral confusion is more likely.

A confusion matrix was constructed to compute overall accuracy, producer's accuracy, user's accuracy, and the Kappa coefficient. The classification results achieved overall accuracies of 86.67% (Kappa = 0.77) in 2016 and 83.33% (Kappa = 0.74) in 2023, indicating substantial agreement between the classified outputs and the reference data. These results confirm that the classification is sufficiently reliable for subsequent spatial and hydrological analysis.

Spatial analysis was conducted to quantify changes in land cover distribution between 2016 and 2023. The classified raster datasets were converted to vector format, and the area of each land cover class was calculated in hectares. Changes in land cover were expressed in both absolute area and percentage terms to evaluate the magnitude and direction of landscape transformation over the seven years.

A spatial overlay analysis was further performed to

compare LULC patterns across time and to examine their relationship with DEM-derived hydrological parameters. This approach enables the identification of areas where land cover changes coincide with runoff-concentration zones, providing a basis for interpreting potential hydrological implications.

Hydrological outputs derived from DEM processing, including flow direction, flow accumulation, drainage networks, and watershed boundaries, were evaluated through spatial consistency checks. The drainage patterns were examined to ensure that flow pathways correspond with topographic gradients and that the delineated watershed boundary reflects realistic terrain-controlled drainage behaviour (Khalid et al., 2021).

UAV imagery acquired in 2025 provided supplementary support for validation and interpretation. The high-resolution observations enabled visual confirmation of land cover types and drainage features, particularly in spectrally ambiguous areas such as riparian zones and partially saturated surfaces. Although UAV data were not used as an independent classification dataset, they improved confidence in the interpretation of spatial relationships between land cover patterns and hydrological characteristics.

Despite satisfactory classification accuracy, some uncertainty remains due to spectral similarities among water bodies, terrain shadows, and saturated soil surfaces, particularly in narrow river channels and riparian zones. Therefore, the results should be interpreted as a spatial approximation of landscape conditions rather than an exact representation of ground reality.

3. RESULT AND DISCUSSION

3.1 Land Use and Land Cover (LULC) analysis for 2016 and 2023

Figure 3 presents the classified Land Use and Land Cover (LULC) map of the Lubuk Yu watershed for 2016, derived from supervised classification of Landsat 8 OLI imagery. Three dominant land cover classes were identified: vegetation, water bodies, and barren land. Vegetation was the predominant class, covering approximately 3.10 km² (75%) of the total watershed area of 4.12 km². Water bodies occupied 0.78 km² (19%), while barren land accounted for 0.24 km² (6%).

The high vegetation proportion in 2016 indicates that the watershed was largely dominated by natural or semi-natural land cover, reflecting relatively limited land disturbance. From a hydrological perspective, dense vegetation enhances rainfall interception, promotes infiltration, and reduces surface runoff and soil erosion. This condition suggests that the watershed likely maintained relatively stable hydrological functioning during this period, with well-regulated

runoff pathways and reduced susceptibility to sediment mobilisation.

Water bodies, comprising 19% of the area, are primarily associated with Sungai Lubuk Yu and its tributary network. Their spatial distribution reflects an established drainage system with continuous hydrological connectivity. These features play an important role in regulating flow pathways and supporting aquatic processes within the watershed.

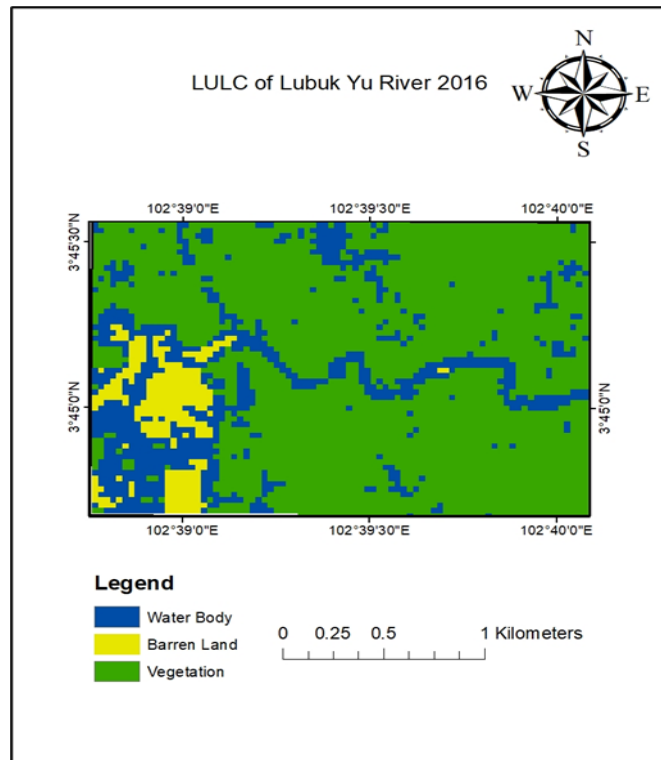


Figure 3: Land Use and Land Cover (LULC) map of the Lubuk Yu watershed in 2016.

The limited extent of barren land (6%) indicates minimal exposure of soil surfaces and relatively low levels of land clearing. Such conditions generally correspond to reduced erosion risk and stable channel conditions, particularly in small tropical catchments.

Figure 4 illustrates the 2023 LULC classification, showing notable spatial and quantitative changes compared to 2016. Vegetation remained the dominant land cover type, declining to approximately 68%, representing a 7% reduction over the seven years. In contrast, water bodies increased to 24% (1.01 km²), while barren land increased slightly to 7%.

The observed reduction in vegetation indicates progressive land surface modification within the watershed. Although moderate in magnitude, this change may influence hydrological processes by reducing infiltration capacity and increasing surface runoff. In small tropical catchments, even modest reductions in vegetation cover can alter runoff generation and accelerate flow concentration along drainage pathways.

The increase in water body extent suggests a change in surface water distribution within the watershed. This may reflect variations in channel width, water levels, or differences in spectral detection between acquisition dates. While the classification results indicate an expansion of water surfaces, the analysis does not directly quantify hydrological variables such as discharge or flow volume. Therefore, the observed increase should be interpreted as a spatial change in water surface extent rather than a direct measure of hydrological flux.

The slight increase in barren land indicates localised land disturbance and exposed surfaces, likely associated with small-scale land-clearing or development activities. Although the change is limited, these areas can contribute to increased runoff and sediment transport, particularly when located near riverbanks or on sloping terrain.

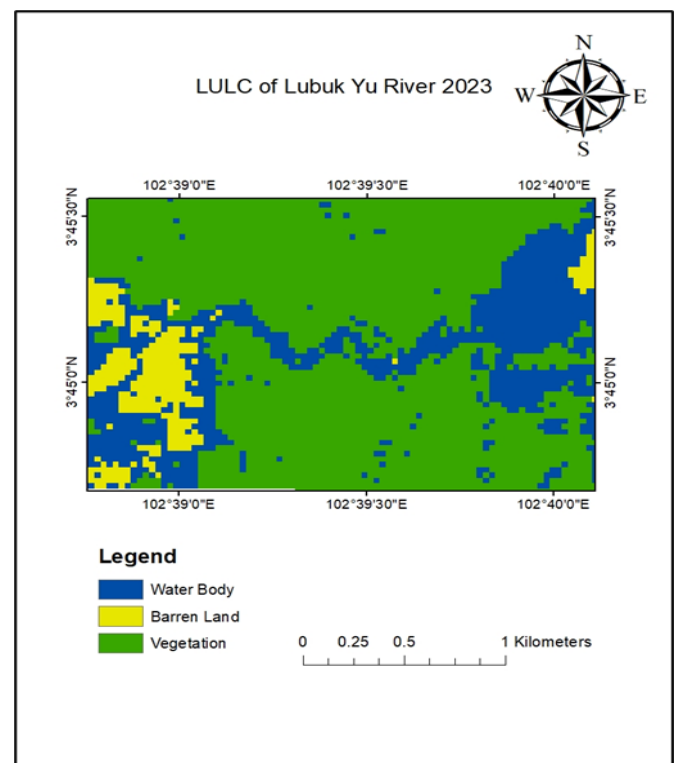


Figure 4: Land Use and Land Cover (LULC) map of the Lubuk Yu watershed in 2023.

Overall, the LULC changes between 2016 and 2023 indicate a gradual transition toward increased land surface exposure and modified vegetation cover. These changes, when considered together with DEM-derived hydrological characteristics, provide a basis for interpreting potential shifts in runoff concentration, drainage behaviour, and watershed response within the Lubuk Yu micro-watershed.

3.2 Land Use and Land Cover (LULC) area observation in 2025 using drone imagery

High-resolution UAV imagery acquired in 2025 was used to provide supplementary visual observations of current

land-use and land-cover conditions within the Lubuk Yu watershed. Although the UAV dataset was collected after the Landsat-based classification years (2016 and 2023), it served as supporting evidence for validating the spatial interpretation of LULC patterns. The UAV observations focused on qualitative assessment of vegetation cover, water bodies, and non-vegetated surfaces at finer spatial resolution than that available from Landsat imagery.

The UAV imagery enabled detailed identification of small-scale landscape features, including riverbank conditions, vegetation fragmentation, and exposed soil surfaces, which are not clearly resolved in medium-resolution (30 m) satellite imagery. These observations enhance confidence in the interpretation of classified LULC outputs, particularly in areas with spectral ambiguity such as riparian zones. However, it should be noted that UAV data were not used as an independent classification dataset, but rather as supplementary validation and interpretation support.

Figure 5 presents UAV imagery of vegetation conditions along the Lubuk Yu River in 2025. The imagery shows localised reduction and fragmentation of vegetation cover, particularly along riverbanks and in areas influenced by human activity. These observations are consistent with the Landsat-based analysis, which indicated a reduction in vegetation cover between 2016 and 2023. From a hydrological perspective, reduced vegetation in riparian zones may increase surface runoff and reduce bank stability, particularly during high rainfall events.

Figure 6 illustrates the distribution of surface water features observed in 2025. The UAV imagery shows widened river sections and localised areas of standing or slow-moving water within low-lying parts of the watershed. These observations are consistent with the increase in water body extent detected in the satellite-based LULC analysis. While these features suggest changes in surface water distribution, the UAV observations are qualitative and do not directly represent changes in hydrological flux or discharge.

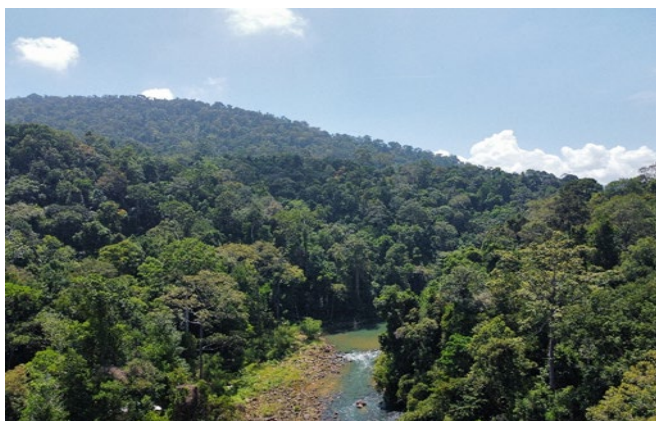


Figure 5: UAV-derived image showing vegetation conditions along the Lubuk Yu River in 2025.



Figure 6: UAV-derived image showing water body conditions within the Lubuk Yu watershed in 2025.

Figure 7 shows land surface conditions associated with exposed and developed areas within the watershed. The UAV imagery reveals localised expansion of built features, access paths, and other impervious surfaces, particularly near river corridors. Although these features are grouped under the barren land category in the satellite-based classification, their presence in UAV imagery provides additional evidence of ongoing land surface modification after 2023.



Figure 7: UAV-derived image showing land use and exposed surfaces within the Lubuk Yu watershed in 2025.

Overall, the UAV observations support the interpretation of LULC changes derived from satellite imagery and provide additional spatial context for understanding recent land surface modifications. When considered alongside DEM-derived hydrological characteristics, these observations help to interpret how localised land cover changes may influence runoff concentration and drainage behaviour within the Lubuk Yu micro-watershed.

3.3 Spatiotemporal change detection of land use and land cover (2016–2023) and observed 2025 trends

The comparative analysis of Land Use and Land Cover (LULC) between 2016 and 2023 indicates gradual but consistent landscape modification within the Lubuk Yu watershed. Table 1 summarises the percentage distributions

of vegetation, water bodies, and barren land for both time periods, with UAV observations in 2025 providing supplementary qualitative insights into recent land-surface conditions.

Table 1: Percentage of land use and land cover classes in 2016 and 2023 with observed 2025 trends

LULC	2016%	2023%	2025 Trends
Vegetation	75	68	Increased
Water Body	19	24	Decreased
Barren Land	6	7	Decreased

Vegetation remained the dominant land cover class, decreasing from 75% in 2016 to 68% in 2023, a 7% reduction. This decline indicates progressive land surface modification within the watershed. From a hydrological perspective, reduced vegetation cover may decrease infiltration capacity and increase surface runoff, potentially enhancing flow concentration along drainage pathways.

UAV observations from 2025 reveal localised vegetation thinning and fragmentation, particularly along river corridors and accessible areas. Although these observations are qualitative, they provide supporting evidence that vegetation reduction identified in the satellite-based analysis may persist beyond 2023.

Water bodies increased from 19% to 24%, representing a 5% expansion in surface water extent. This change may be associated with variations in channel width, water levels, or differences in spectral detection between acquisition periods. However, given the moderate spatial resolution of Landsat imagery, part of this increase may also reflect spectral confusion between water surfaces, terrain shadows, and saturated soils. Therefore, the detected increase should be interpreted cautiously as a spatial change in surface water extent rather than a direct measure of hydrological flux.

Barren land increased slightly from 6% to 7%, indicating localised soil surface exposure and land disturbance. UAV observations further suggest the presence of infrastructure, access paths, and other impervious features near river corridors. These surfaces can contribute to increased runoff and sediment transport, particularly during high rainfall events.

The classification's reliability was evaluated using a confusion matrix, as shown in Table 2. The results indicate overall accuracies of 86.67% (Kappa = 0.77) for 2016 and 83.33% (Kappa = 0.74) for 2023, demonstrating substantial agreement between classified outputs and reference data.

To further examine transition pathways, a land cover change matrix was generated for the 2016–2023 period (Table 3). The results indicate that portions of vegetated areas

were converted into water bodies and barren land, reflecting localised land cover transitions within the watershed.

Table 2: Accuracy assessment of LULC classification

Land Cover Class	User Accuracy (2016) %	Producer Accuracy (2016) %	User Accuracy (2023) %	Producer Accuracy (2023) %
Water Body	50	100	50	100
Barren Land	100	85.71	100	100
Vegetation	100	84.21	100	68.75
Overall Accuracy	86.67		83.33	
Kappa Coefficient	0.77		0.74	

Table 3: LULC change matrix (2016-2023)

2016/2023	Vegetation	Water Body	Barren Land
Vegetation	2.70 km ²	0.30 km ²	0.10 km ²
Water Body	0.05 km ²	0.65 km ²	0.08 km ²
Barren Land	0.03 km ²	0.06 km ²	0.15 km ²

These transitions indicate a shift toward increased land surface exposure and redistribution of water-covered areas. When considered alongside DEM-derived hydrological characteristics, such changes suggest potential modification of runoff concentration patterns, particularly in areas where vegetation loss coincides with zones of higher flow accumulation.

Despite the relatively high classification accuracy, some uncertainty remains due to mixed pixels, spectral similarity among land cover classes, and seasonal variability. Therefore, the LULC maps should be interpreted as spatial approximations of landscape conditions rather than exact representations of ground reality.

3.4 Flow direction analysis

Figure 8 presents the DEM-derived flow direction map of the Lubuk Yu watershed generated using the deterministic eight-direction (D8) algorithm. This approach assigns each raster cell a flow path toward the neighbouring cell with the steepest downslope gradient, enabling representation of surface runoff routing and drainage structure across the watershed.

The flow direction results indicate that surface runoff generally originates from higher elevation areas in the eastern and northeastern parts of the watershed and converges toward the western outlet along Sungai Lubuk Yu. This pattern reflects the basin's overall topographic gradient and confirms the consistency of DEM-derived flow modelling with the physical terrain.

The spatial distribution of flow vectors shows a dense and convergent drainage pattern, indicating a well-developed headwater system. Areas of strong flow convergence correspond to zones of higher flow accumulation, which are typically associated with channel initiation and increased potential for runoff concentration and erosion. These areas represent critical zones for understanding drainage

development and potential sediment transport pathways within the watershed.

A spatial relationship is observed between flow direction patterns and LULC distribution. Vegetated areas, particularly in the upper catchment, tend to exhibit more diffuse flow patterns, reflecting vegetation's role in reducing runoff velocity and enhancing infiltration. In contrast, areas with reduced vegetation cover or increased barren land exhibit more concentrated flow pathways, suggesting higher runoff efficiency and a greater potential for surface erosion.

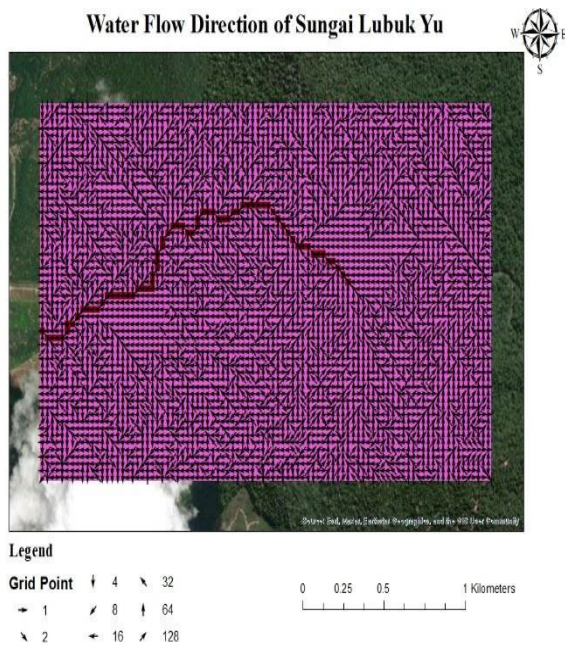


Figure 8: DEM-derived flow direction map of the Lubuk Yu watershed.

The integration of flow direction analysis with LULC results indicates that observed vegetation reduction may contribute to enhanced runoff concentration along existing drainage pathways. This effect is particularly relevant in small tropical watersheds, where localised land surface changes can significantly influence flow routing and watershed response.

Overall, the flow direction analysis provides a terrain-based framework for interpreting runoff pathways and drainage organisation. When considered together with morphometric indices and LULC changes, these results support the interpretation that land cover modification may influence runoff concentration and sediment transport dynamics within the Lubuk Yu watershed.

3.5 Watershed delineation and stream order analysis

Watershed delineation and stream-order analysis were performed using DEM-derived hydrological modelling to

define the basin boundary and characterise the hierarchical structure of the drainage network. Stream ordering was conducted using the Strahler method. The resulting watershed boundary and stream-order distribution are presented in Figure 9, while quantitative stream characteristics are summarised in Table 4.

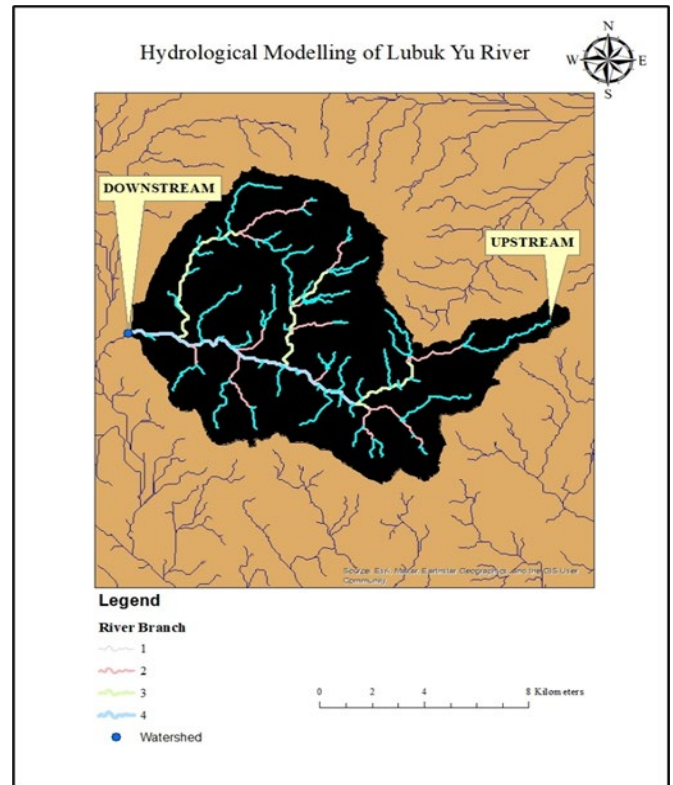


Figure 9: Watershed delineation and stream-order map of the Lubuk Yu watershed.

The Lubuk Yu watershed is dominated by first-order streams, with 62 individual channels accounting for 68.34 km of total stream length (approximately 58% of the network). Across all stream orders, the drainage network comprises 123 stream segments totalling 118.27 km within a 4.13 km² catchment. These values correspond to a drainage density of 28.64 km km⁻² and a stream frequency of 29.78 streams km⁻², indicating a highly dissected headwater system with rapid concentration of surface runoff. As these metrics are derived from DEM-based extraction, they should be interpreted as relative indicators of drainage organisation rather than direct hydraulic measurements.

Table 4: Stream order classification and characteristics of the Lubuk Yu Watershed

Stream Order	Number of Streams	Total Stream Length (km)	Total Stream Length (%)	Bifurcation Ratio	Remarks
1 st	62	68.34	57.75	2.95	1 st /2 nd
2 nd	21	23.18	19.60	1.00	2 nd /3 rd
3 rd	21	16.07	13.59	1.11	3 rd /4 th
4 th	19	10.68	9.03	-	Highest Order

The progressive reduction in stream number and total length with increasing order is consistent with established fluvial geomorphological principles. Lower-order streams dominate the drainage network, reflecting the importance of headwater channels in controlling runoff generation and initial flow routing. These channels play a critical role in conveying surface runoff to higher-order streams, particularly during high-rainfall events.

Bifurcation ratios between successive stream orders range from 1.00 to 2.95, with an average value of approximately 1.69. These relatively low to moderate values suggest that the drainage network is primarily controlled by local topographic conditions, with limited structural influence. At the same time, the values reflect sensitivity to DEM resolution and the selected flow accumulation threshold used for stream extraction.

From a hydrological perspective, the dominance of first-order streams, combined with high drainage density and stream frequency, indicates a responsive watershed system where runoff is rapidly concentrated through a dense network of headwater channels. This condition implies that even moderate land cover changes may significantly influence runoff pathways and sediment transport processes, particularly in upper catchment areas.

Overall, the morphometric characteristics of the Lubuk Yu watershed reinforce its classification as a tropical micro-watershed with high sensitivity to land surface modification. When considered alongside LULC changes, these results provide important insight into how terrain structure and land cover jointly influence drainage behaviour and hydrological response within the basin (Ahmad et al., 2025; Ping et al., 2024).

3.6 Relationship between land use changes and hydrological characteristics

The integration of Land Use and Land Cover (LULC) dynamics with DEM-derived hydrological parameters provides a spatially explicit basis for interpreting how landscape modification influences watershed behaviour in the Lubuk Yu micro-catchment. Between 2016 and 2023, vegetation cover declined by approximately 7%, accompanied by increases in water bodies (5%) and barren land (1%). Although moderate in magnitude, these changes are hydrologically significant within a small, highly responsive tropical watershed.

Vegetation plays a key role in regulating hydrological processes by enhancing infiltration, reducing runoff velocity, and stabilising soil surfaces. A reduction in vegetation cover is therefore expected to decrease infiltration capacity and increase the proportion of surface runoff. This effect is reflected in the spatial correspondence between vegetation

loss and zones of higher flow accumulation identified in the DEM analysis.

Overlay analysis indicates that areas of vegetation reduction frequently coincide with flow accumulation pathways, particularly along tributary corridors and drainage convergence zones. Flow accumulation, representing the cumulative upstream contributing area, is widely used as a proxy for runoff concentration. The co-location of vegetation loss and high flow accumulation suggests an increased potential for concentrated surface runoff and localised erosion in these areas.

The hydrological response of the watershed is further influenced by its morphometric characteristics. The dominance of first-order streams, combined with high drainage density and stream frequency, indicates a dense headwater network that rapidly conveys runoff. In such systems, even moderate land cover modification can alter runoff routing, shorten response time, and increase the likelihood of rapid flow concentration along drainage pathways.

The observed increase in barren land, although limited in extent, represents areas of exposed soil that are more susceptible to erosion under the high rainfall typical of tropical environments. When these areas are located near drainage pathways, they may contribute disproportionately to sediment transport and channel instability.

It is important to recognise that the relationships identified in this study are based on spatial association rather than direct hydrological simulation. While the observed patterns provide evidence of potential linkages between land cover change and runoff behaviour, they should be interpreted as indicative rather than causal. Further investigation using process-based hydrological models (e.g., SWAT or HEC-HMS) and field measurements would be required to quantify these relationships under varying climatic and land use conditions.

Overall, the results demonstrate that even moderate land cover changes can influence runoff concentration and drainage behaviour in a tropical micro-watershed. The study highlights the sensitivity of headwater systems to localised land surface modification and underscores the importance of maintaining vegetation cover, particularly in upstream and riparian zones, to sustain hydrological regulation and reduce erosion risk. These findings provide a process-oriented basis for supporting watershed management, land-use planning, and conservation strategies in the Lubuk Yu region.

4. CONCLUSION

This study applied GIS and remote sensing techniques to evaluate spatiotemporal LULC changes and terrain-derived hydrological characteristics within the Lubuk

Yu watershed, Pahang. Using multi-temporal Landsat 8 imagery (2016–2023) and SRTM DEM data, the study provided a spatially integrated assessment of landscape transformation and watershed response in a tropical micro-catchment.

The results indicate a measurable shift in land cover over the seven years, with vegetation decreasing from 75% to 68%, accompanied by increases in water bodies (19% to 24%) and barren land (6% to 7%). These changes reflect progressive land-surface modification. It also suggests potential alterations in hydrological processes, particularly through reduced infiltration capacity and increased surface runoff. UAV observations in 2025 further support these findings by indicating continued vegetation fragmentation. UAV also found a localised expansion of exposed and developed surfaces.

DEM-based hydrological analysis revealed a well-defined drainage system dominated by first-order streams. This is characterised by high drainage density and stream frequency, indicating a highly responsive headwater network. The spatial integration of LULC and hydrological outputs shows that areas of vegetation reduction frequently coincide with zones of higher flow accumulation. It suggests increased potential for runoff concentration and localised erosion within the watershed.

This study demonstrates that even moderate land cover changes can influence runoff pathways and drainage behaviour in small tropical watersheds. The findings highlight the sensitivity of headwater systems to localised land surface modification. It also reinforces the importance of maintaining vegetation cover, particularly in upstream and riparian zones, to sustain hydrological regulation and reduce erosion risk.

Several limitations should be acknowledged. The simplified three-class LULC scheme derived from 30 m Landsat imagery may not fully capture fine-scale land-surface heterogeneity. In addition, the hydrological assessment is based on DEM-derived spatial indicators rather than process-based modelling. It therefore represents potential rather than directly simulated hydrological responses. Future research should incorporate physically based models such as SWAT or HEC-HMS. Together with higher-resolution datasets, it can quantify runoff dynamics, sediment transport, and the uncertainty associated with land-use change.

Overall, this study provides baseline evidence for understanding land cover–hydrology interactions in the Lubuk Yu watershed. It also offers practical insights to support watershed management, land-use planning, and environmental monitoring in tropical catchments.

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