

Catchment Delineation and LULC Classification of the Upper Catchment of the Timah-Tasoh Reservoir Using DEM and GIS

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Abstract

The catchment plays a crucial role in delineating basin boundaries and creating sub-basins within it. By using a geographic information system (GIS), it becomes capable of identifying the sub-catchments within the Timah-Tasoh reservoir. GIS has evolved into an indispensable tool for mapping and evaluating ecosystems in a given area. By employing various parameters, significant hydrological processes can be identified and quantified in both small and large catchment areas. This study aims to determine the hydrological characteristics of the reservoir's sub-catchments. The catchment is delineated using the digital elevation model (DEM), and this analysis is performed through ArcGIS. The result indicates that ArcGIS 10.7.1 can determine the catchment delineation and land use classification for the Timah-Tasoh reservoir. Following the delineation procedure, 19 sub-catchments covering a total area of 183.34 km² were identified, and the land cover was reclassified into five categories: agriculture, built-up areas, forest, vacant land and water bodies. Therefore, considering the possibility of utilising ArcGIS for the future expansion of this study can enhance the understanding.

1. Introduction

Hydrology supports water resources planning, management and regulation through the application of engineering and geographical principles. Computerised hydrologic models have become important tools, not only for better understanding the hydrologic cycle, but also for faster problem solving in hydrology, such as ungauged catchments that are hard to figure out [1]. In recent years, GIS and satellite remote sensing data have been incorporated into such models [2]. Data and associated characteristics spatially referenced to the earth can be captured, stored, analysed, and managed using GIS. The importance of combining GIS with hydrological modelling has grown due to the value of geographically distributed data and analysis that can be gained from it. GIS has become an essential tool for mapping and evaluating how ecosystems are provided in an area [3]. Catchment size, catchment slope, main channel length and stream length are a few parameters that can be used to identify and parameterise critical hydrological processes across small and large catchment areas [4].

In addition, the utilisation of openly accessible satellite imagery and datasets enables GIS to conduct analyses of ecosystem services in regions of the world where other data sources may be scarce [5]. GIS effectively illustrates the dispersion of ecosystem services across a landscape, allowing for comparisons of multiple ecosystem service distributions concerning shifts in drivers of change and other social-ecological factors. Moreover, it facilitates the investigation of how changes in land use or land cover, land management, and human population affect ecosystem service provision, and utilisation [6].

2. Methods

2.1 Description of Study Area

The study area is located in the upper part of the sub-catchments of the Timah-Tasoh reservoir, as shown in Fig. 1. The reservoir is the largest reservoir in Perlis, Malaysia, which lies approximately 13 km² north of Kangar town, and it is near the Thailand border. The reservoir has a large storage capacity with an average surface area of 13.33 km² and a storage capacity of 40 million m³. The Timah-Tasoh reservoir helps prevent floods and serves other purposes like supplying water and offering recreational activities. These reservoirs also get water from the Tasoh and Pelarit rivers, which together contribute about 97 million m³ of water per year [7]. The stream network and catchment in this study area will be modelled based on a digital elevation model (DEM).

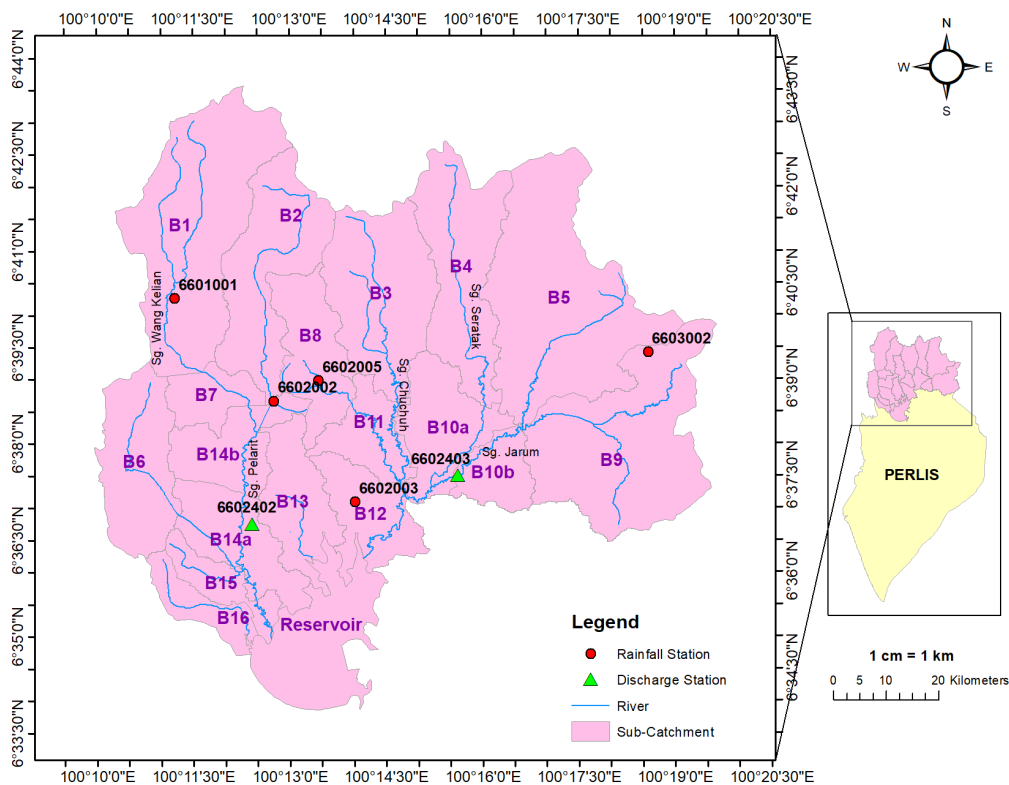


Fig. 1 Location of study area

2.2 Data Source

The Shuttle Radar Topography Mission (SRTM) DEM 30m for Perlis was downloaded from the United States Geological Survey (USGS) open data source (<https://earthexplorer.usgs.gov/>) and served as the primary information source due to its higher resolution and availability on the internet. This DEM data was used to delineate the sub-catchments in the study area. DEM is a digital representation of the Earth's surface, which shows the elevation values of the terrain over a specified area [8]. It also provides information about the topography and relief of the land, indicating the variations in elevation. Fig. 2 shows the DEM.

The classification process and analysis of the different LULC classes were conducted using Landsat 8 satellite imagery. Satellite images consist of digital photographs or raster data captured by sensors on Earth-orbiting satellites, offering a visual representation of the Earth's surface, including natural features, land cover types, and human-made structures [9]. Land cover data sets spanning from 2000 to 2021 were acquired from USGS (<https://earthexplorer.usgs.gov/>). Landsat satellite images were chosen based on their quality, particularly favouring those with minimal cloud cover, as depicted in Fig. 3.

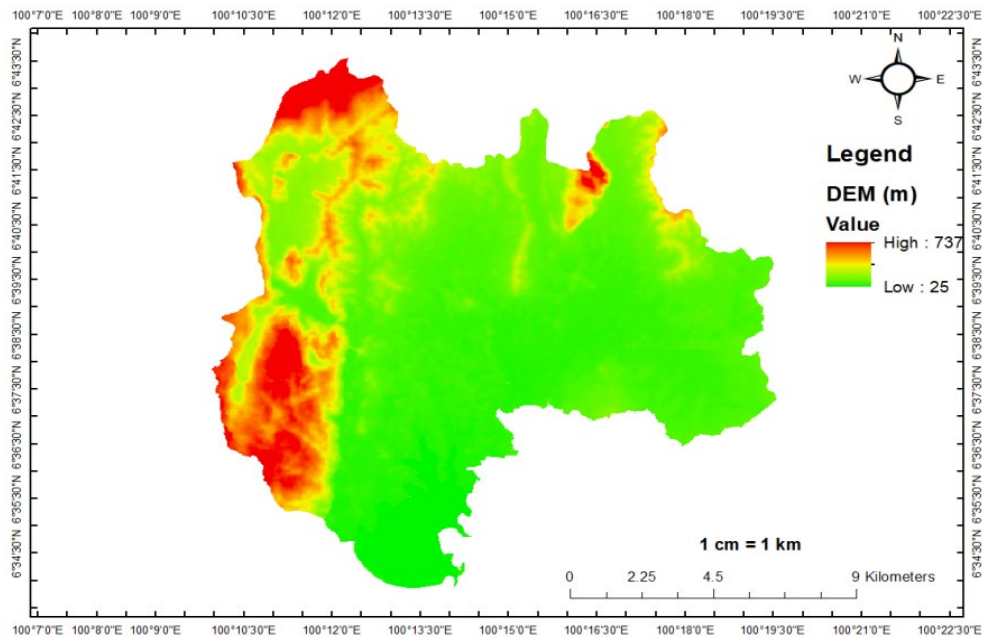


Fig. 2 DEM for Perlis sub-catchment

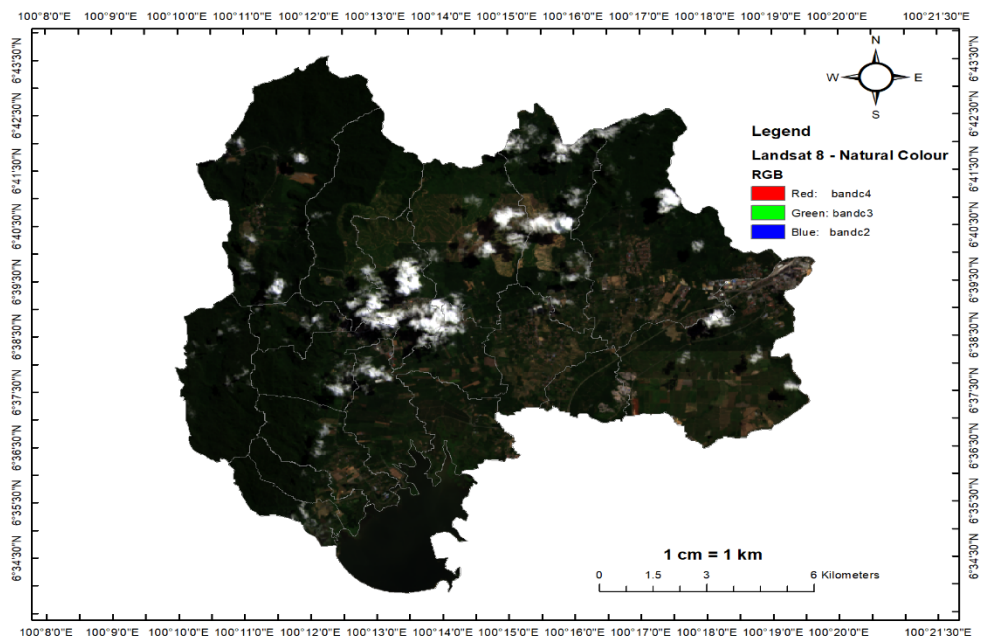


Fig. 3 Satellite image from the Landsat 8 satellite

2.3 Delineation of Catchments

The steps followed in this study for delineation of catchment using DEM are presented in Fig. 4. In terrain pre-processing, the DEM sinks were filled, flow direction and flow accumulation were estimated, and catchments were separated. The delineation process was applied to define the boundaries of the Timah-Tasoh reservoir, subsequently dividing it into multiple sub-catchments to facilitate detailed analysis. Furthermore, the modifications of the study area were made by using ArcGIS by the authors.

2.4 Land Use Classification

In this study, supervised classification was performed. Supervised classifications rely heavily on human input, whereas unsupervised classifications are determined by software. The supervised classification is a process of using samples of known identity to classify pixels of unknown identity [11]. It is commonly used for LULC mapping, image classification, and various other spatial analysis tasks. To begin the process, the required data,

such as satellite imagery specific to the study area, must be obtained. Subsequently, it is crucial to carefully select an ample number of representative training samples of each land cover class to achieve precise classification results. Obtain the data that you want to classify, such as satellite imagery, based on the study area. A signature file was generated to hold all the training samples that had been collected. For the land use classification, the Maximum Likelihood classification was employed. Additionally, as highlighted in previous research by Richards & Jia [12], supervised classification stands out as the predominant method for quantitative analysis of remote sensing imagery. Upon analysis of the study area, five different land use classes were identified, which included agriculture, built-up areas, forest, vacant land and water bodies. In this study, supervised classification is run in ArcGIS with the ArcGIS Spatial Analyst extension.

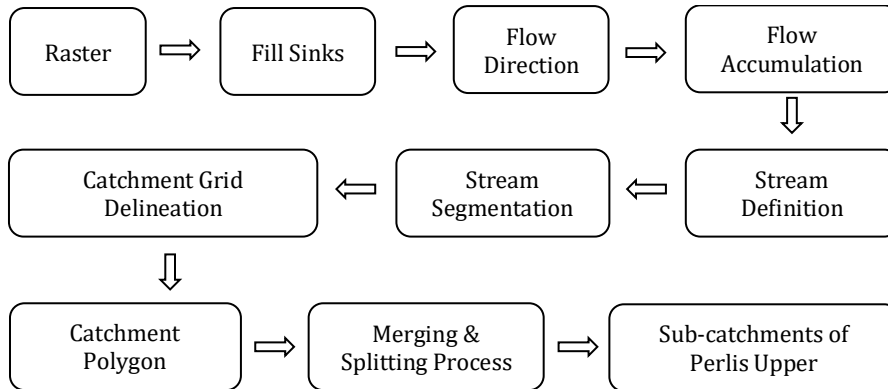


Fig. 4 Flow to develop the delineation of the catchment [10]

3. Result and Discussion

3.1 Delineation of the Upper Catchment of the Timah-Tasoh Reservoir

Catchment delineation has been done by using ArcGIS. The Digital Elevation Model (DEM) of the upper catchment of the Timah-Tasoh reservoir was downloaded from the United States Geological Survey (USGS) website (<https://earthexplorer.usgs.gov/>). Once downloading the DEM from USGS, it runs some processes to generate the sub-catchments and relevant hydrological characterisation. The final results of the catchment area and parameter can be seen in the attribute of the output shapefile. Based on the catchment delineation, it generated 19 sub-catchments, as shown in Fig. 5. The characteristics for all the sub-catchments have been shown in Table 1.

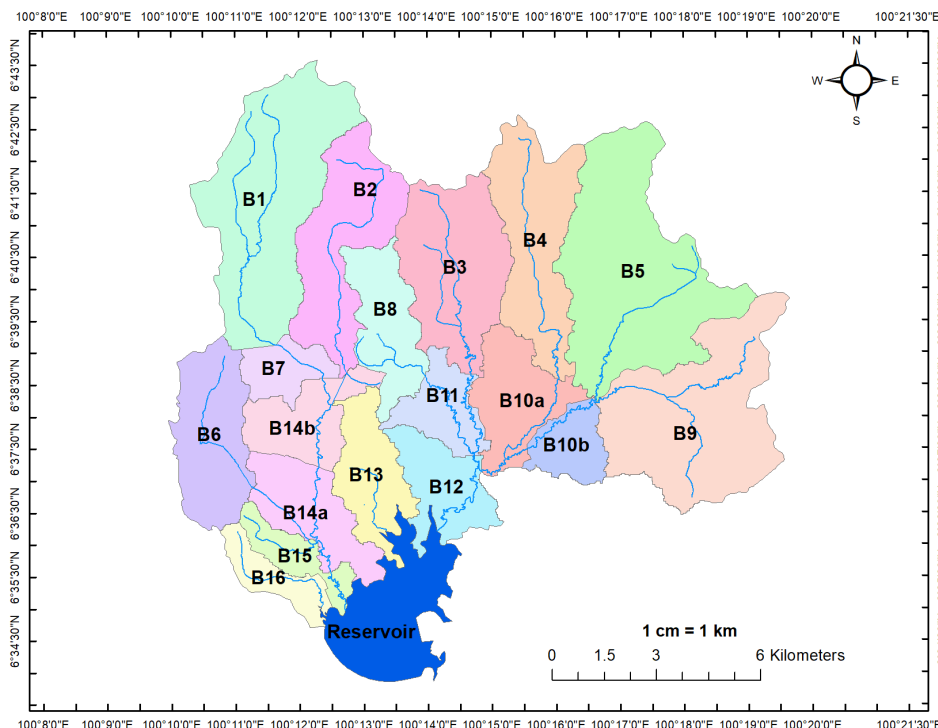


Fig. 5 Sub-catchments of the upper catchment

Based on [Table 1](#), it can be concluded that the total area of the sub-catchments is 183.34 km². Furthermore, it also shows that the largest sub-catchment is B5, with 23.48 km², and the smallest sub-catchment is B15, with 3.38 km². Zardari et al. [10] determined that having the information is an example of how utilising one advantage of GIS in the study for gathering information about the catchment may benefit. In addition, the researchers did not need to measure the area of each of the sub-catchments. Employing this software allowed for time and effort savings that might be realised. The elevation data of the sub-catchments were used to calculate the slope. According to the result in [Table 1](#), it can be seen that B16 has the highest slope, while B12 has the smallest slope, with the range value of 3.35% and 0.15%, respectively.

Table 1 Characteristics of the upper sub-catchment

| Sub-Catchment | Area (km ²) | Upstream (m) | Downstream (m) | Slope Catchment (%) |
|---------------|-------------------------|--------------|----------------|---------------------|
| B1 | 21.14 | 720 | 180 | 2.02 |
| B2 | 12.33 | 320 | 80 | 0.91 |
| B3 | 13.44 | 300 | 80 | 0.98 |
| B4 | 12.58 | 140 | 80 | 0.22 |
| B5 | 23.48 | 360 | 40 | 1.02 |
| B6 | 9.72 | 460 | 320 | 0.82 |
| B7 | 3.55 | 260 | 180 | 0.72 |
| B8 | 7.25 | 220 | 40 | 0.89 |
| B9 | 19.93 | 180 | 60 | 0.44 |
| B10a | 7.62 | 140 | 40 | 0.54 |
| B10b | 3.91 | 140 | 40 | 0.89 |
| B11 | 4.81 | 40 | 10 | 0.19 |
| B12 | 6.29 | 40 | 10 | 0.15 |
| B13 | 6.81 | 100 | 40 | 0.28 |
| B14a | 7.22 | 280 | 40 | 1.28 |
| B14b | 6.26 | 180 | 40 | 0.83 |
| B15 | 3.38 | 500 | 40 | 3.23 |
| B16 | 3.39 | 460 | 40 | 3.35 |
| Reservoir | 10.23 | - | - | 0.00 |
| Total | 183.34 | | | |

3.2 Land Use and Land Cover in Upper Catchment

As stated in [Fig. 6](#), [Fig. 7\(a\)](#) and [Table 2](#), the data were obtained from the supervised classification of land use and land cover (LULC). The land cover of the study region was reorganised into five different groups, including agricultural, built-up areas, forest, vacant land, and water bodies.

The land use in this study area is mainly forest. Forest in Perlis is located in the Northwest of Perlis and represents 85.13 km² which is 46.43 % of the study area. The forest in the state of Perlis can be classified as a Wildlife Protection Forest, State Park Forest, Water Catchment Forest, Land Protection Forest, and Permanent Reserve Forest [13]. Land use in Perlis is dominated by agriculture and followed by forest. However, the forest has proven to be the most effective land use in this study compared to agriculture. Sub-catchment B1 (17.80 km²) is the highest area for the forest class, followed by B2 (9.82 km²), compared to the other sub-catchments. It is because the water catchment forest is located at the B1.

Sub-catchment B1 (17.80 km²) has the largest forest area compared to the other sub-catchments. The forest in sub-catchment B1 is the water catchment forest, which must be protected. Water catchment areas, like forests and rivers, play a crucial role in ensuring a consistent water supply for all of Earth's life [14]. Razali et al. [15] stated that a water catchment area is defined as an area of land bounded by mountains or hills over which rainwater flows to the low point and then into a dam, river, bay, or ocean. Meanwhile, as this study primarily considers the upper catchment, the forest has established itself as the dominant in this section, and agriculture accounts for 33.40 %. Based on the previous studies by Ismail [16] and Abdullah et al. [17], the land adjacent to the reservoir and its upstream catchment predominantly serves agricultural purposes, cultivating crops such as rubber, rice, sugar cane and timber (see [Fig. 7\(b\)](#)). By comparing [Fig. 7\(a\)](#) and [Fig. 7\(b\)](#), this study is able to validate the land use classification between the previous and present studies.

Built-up areas comprise 13.71% of the study area and are reclassified into residential, transportation, and industrial areas. The sub-catchment area of B5 and B9 is the highest compared to other sub-catchments since it is

located in Padang Besar. Padang Besar is a Malaysian border town, and it is located in the northern part of Perlis, which shares a border with Thailand's province of Songkhla. Padang Besar is well-known for its border shopping activities, and the large market is known as Padang Besar Business Arcade Complex (PBAC). Thus, it is acceptable that B5 and B9 are the highest due to commercial industries in Perlis. Fig. 6 shows the percentage of the LULC in the study area.

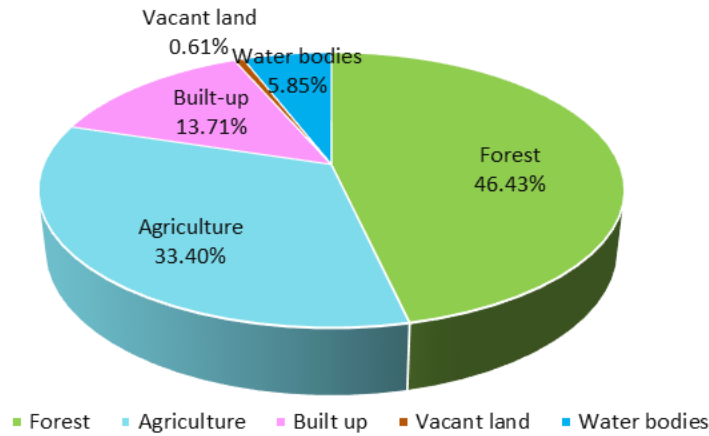


Fig. 6 Percentage of LULC of the upper catchment

Table 2 Classification of LULC of the upper catchment

| Sub-Catchment | Land Use Category | | | | | Total area (km ²) |
|-----------------|--------------------------------|-----------------------------|---------------------------|--------------------------------|---------------------------------|-------------------------------|
| | Agriculture (km ²) | Built-up (km ²) | Forest (km ²) | Vacant land (km ²) | Water bodies (km ²) | |
| B1 | 2.32 | 0.97 | 17.80 | 0.05 | 0.00 | 21.14 |
| B2 | 1.98 | 0.53 | 9.82 | 0.00 | 0.00 | 12.33 |
| B3 | 5.53 | 1.78 | 6.08 | 0.05 | 0.00 | 13.44 |
| B4 | 5.93 | 1.44 | 5.19 | 0.02 | 0.00 | 12.58 |
| B5 | 9.27 | 4.79 | 9.37 | 0.01 | 0.04 | 23.48 |
| B6 | 0.47 | 0.04 | 9.18 | 0.01 | 0.02 | 9.72 |
| B7 | 0.43 | 0.31 | 2.79 | 0.00 | 0.02 | 3.55 |
| B8 | 3.26 | 1.87 | 1.99 | 0.13 | 0.00 | 7.25 |
| B9 | 13.09 | 5.66 | 1.11 | 0.00 | 0.07 | 19.93 |
| B10a | 3.71 | 1.32 | 2.55 | 0.01 | 0.03 | 7.62 |
| B10b | 1.99 | 0.91 | 0.99 | 0.02 | 0.00 | 3.91 |
| B11 | 2.83 | 0.80 | 1.18 | 0.00 | 0.00 | 4.81 |
| B12 | 3.14 | 1.18 | 1.48 | 0.11 | 0.38 | 6.29 |
| B13 | 2.87 | 1.33 | 2.20 | 0.25 | 0.15 | 6.81 |
| B14a | 2.27 | 0.99 | 3.79 | 0.06 | 0.11 | 7.22 |
| B14b | 0.49 | 0.69 | 4.68 | 0.40 | 0.00 | 6.26 |
| B15 | 0.80 | 0.22 | 2.21 | 0.00 | 0.15 | 3.38 |
| B16 | 0.51 | 0.18 | 2.56 | 0.00 | 0.13 | 3.39 |
| Reservoir | 0.32 | 0.12 | 0.16 | 0.00 | 9.63 | 10.23 |
| Total & Average | 61.22 | 25.13 | 85.13 | 1.12 | 10.73 | 183.33 |

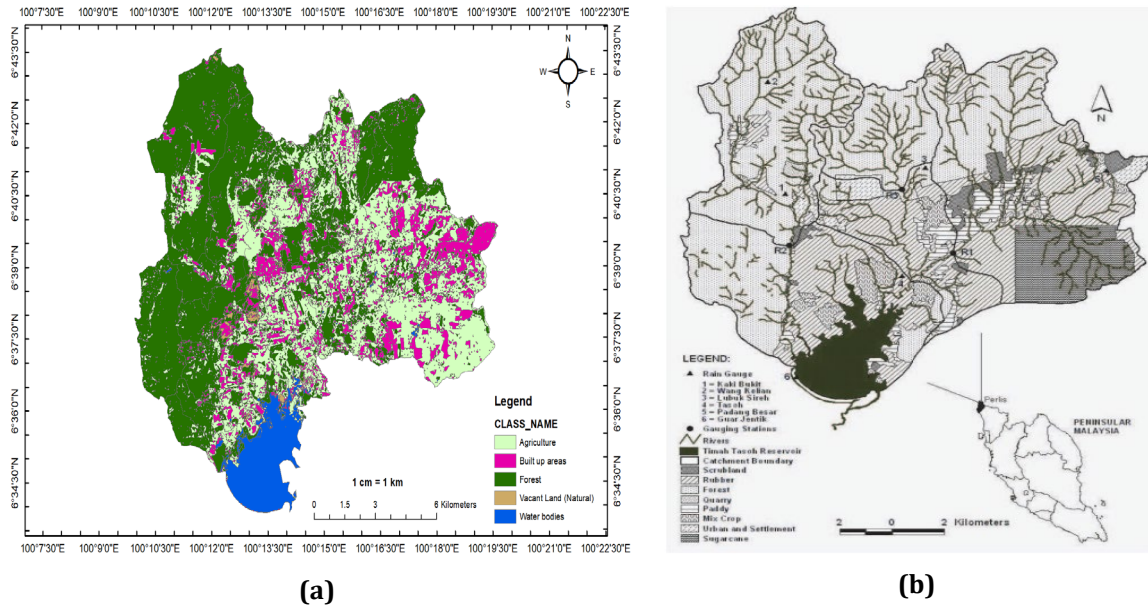


Fig. 7 Land use classification for (a) This study; (b) By [16] and [17]

4. Conclusion

In conclusion, ArcGIS can be used to automatically delineate the catchment boundary. It was successfully applied in this study to complete the delineation of the catchment area. The process identified a total of 19 sub-catchments, including the Timah-Tasoh reservoir, ranging in area from 3.38 km² to 23.48 km², with a total area of 183.34 km². Based on the results, B16 had the highest slope at 3.35%, while B12 had the lowest at 0.15%. regarding land use in this study area, it is predominantly forest (44.63%), followed by agriculture (33.40%), built-up (13.71%), water bodies (5.85%) and vacant land (0.61%). Furthermore, with the aid of the ArcGIS application, more information of this type can be collected from the sub-catchments. Thus, utilising ArcGIS for further expansion of this work is a possibility in the future. Therefore, with the support of a precise dataset, the catchment delineation results are consistent with the realistic hydrological process.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Nor Aisyah Syafiqah Nordin, Zulkarnain Hassan; **data collection:** Ain Nihla Kamaruzaman, Ag Shaffie Ag Ahmadni; **analysis and interpretation of results:** Nor Aisyah Syafiqah Nordin, Norazian Mohamed Noor; **draft manuscript preparation:** Nor Aisyah Syafiqah Nordin. All authors reviewed the results and approved the final version of the manuscript.

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