SINERGI Vol. 29, No. 2, June 2025: 437-446
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2025.2.014

Identifying degradation pathways at Sembrong Dam, Johor: insights from Sentinel-2 satellite imagery and NDVI analysis

Mustaffa Anjang Ahmad[1]*, Muhammad Dzikri Kahlid[1], Muhammad Haziq Izzuddin Mohd Hussin[1], Mohd Adib Mohammad Razi[2], Ebrahim Hamid Hussein Al-Qadami[2], Mokhamad Nur Cahyadi[3]
[1]Center of Applied Geomatic and Disaster Prevention (CAGeD), Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Malaysia
[2]Eco-Hydrology Technology Research Center (Eco-Hytech), Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Malaysia
[3]Geomatics Engineering Department, Institut Teknologi Sepuluh Nopember (ITS), Indonesia

Abstract
The study is to evaluate the catchment area mapping at Sembrong Dam in Johor, Malaysia and identify potential transit pathways contributing to dam water degradation while implementing targeted mitigation works. The analysis involved the surface runoff patterns and topographical/geographic data via a digital elevation model (DEM), providing insights into terrain characteristics, slope, and flow directions to hydrological dynamics that significantly contribute to water resource management. This study focuses on producing the catchment area map with satellite imagery and defining the transit pathway that potentially causes water degradation in a reservoir. The analysis uses satellite images from sentinel-2 processing to generate a detailed runoff map and DEM of the catchment area surrounding the dam. The study uses Red Bands (RED) and Near-Infrared Bands (NIR) to process sentinel satellite images to create NDVI maps. Data is uploaded as Raster data in QGIS, and NDVI calculations are performed to transform raw satellite data into an index for vegetation health. NDVI values are classified into different colour classes to visualize the condition of the study area. High NDVI values indicate higher concentrations of agriculture nutrients, potentially triggering eutrophication in watersheds through surface runoff. The study analyzed a 66.89 km2 reservoir catchment area using runoff maps. NDVI analysis showed vegetation density and plant health, with robust vegetation in the dam-surrounded region with an NDVI value of 0.8. However, due to its narrow geography and deep lakes, the northeastern region is slightly polluted and susceptible to algae growth. The study aims to improve understanding of LULC and water conditions by analyzing pollution levels using remote sensing data, DEM, and NDVI for mitigation strategies.

Keywords:
Catchment area mapping;
Digital elevation model (DEM);
Normalized Difference Vegetation Index (NDVI);
Sembrong Dam;
Surface runoff analysis;
Water degradation;

Article History:
Received: August 29, 2024
Revised: October 16, 2024
Accepted: November 1, 2024
Published: May 15, 2025

Corresponding Author:
Mustaffa Anjang Ahmad
Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Malaysia
Email: mustafa@uthm.edu.my

INTRODUCTION

The Sembrong Reservoir, located in Malaysia, is vital in flood control and water supply for the surrounding area. Reservoirs behave more like natural lakes, with water quality affected mostly by the geology of the watershed and land use within the watershed [1]. Following a precipitation event, it obtains most of its water intake from surface water runoff. Watersheds are crucial for the hydrological cycle, producing clean freshwater resources. As a result, water treatment expenses have increased due to the growth of agricultural and forestry zones near watersheds, causing contaminated drinking water. The pollution may often be caused by agricultural fertilizers, pesticides, and farm waste, which contain ammonia, potassium, and phosphate and are used to boost production rates. Excessive amounts of ammonia, nitrogen, and phosphorus cause eutrophication by fostering algal blooms in water bodies, which declines the quality of clean water supply. These substances are linked to pollution events, biodiversity loss, and food resource contamination and can directly and indirectly impact human health [2]. The nutrients reach the reservoir by stormwater runoff from land to inland, where the plantation ground is highly concentrated with nutrients from fertilizers and pesticides. In addition, nearly the whole area surrounding this reservoir has a slope heading to the watershed since this reservoir is a surface water harvesting to collect and store surface water.

Land use land cover (LULC) change impacts on surface runoff to dams have been extensively studied. Recent studies [3][4] found that urbanization and agricultural growth significantly affect streamflow and water quality, with agricultural expansion increasing nutrient and sediment loads and urbanization increasing impermeable surfaces and surface runoff. The study [5] has demonstrated that urbanization in the Three Gorges Reservoir Area led to increased sediment output and surface runoff due to decreased infiltration. These studies emphasize the importance of managing land use change to improve water resource sustainability in dammed watersheds. Additionally, catchment characteristics such as soil type, topography, and climate play a significant role in surface runoff. Previous research [6] highlighted the rise in surface runoff and sediment output resulting from land use change in a Mediterranean watershed, with extreme weather events exacerbating these effects. The study outcomes underline the importance of considering catchment characteristics and implementing sustainable land use strategies to minimize surface runoff and sediment production in dams.

The impact of climate change on the surface is runoff to dams. Furthermore, Malaysia is also one of the countries in the Southeast Asian region that has experienced climate change that has affected agriculture production [7][8]. Unpredictable changes in Malaysia's climatic conditions have surged fertilizer use to overcome the sluggish output problem [9].

This production pattern may result in inadequate supply as the population continues to rise over time, directly influencing rising demand. As a result, agricultural activities have increased in the recent decade, and excessive fertilization has caused serious environmental issues such as eutrophication linked to inorganic fertilizers. This makes the agricultural soil highly concentrated with agricultural nutrients plus unpredictable precipitation events, especially heavy precipitation events causing more nutrients flow into watersheds throughout the surface runoff, triggering eutrophication.

Previous studies only focused on the reservoir's water quality and came out with the trophic status of each part of the reservoir, as shown in Figure 1. This study is conducted to identify the part of land used around this reservoir that dominantly contributes to water degradation. This reservoir has two major inlets (Sungai Sembrong in the northeast region and Sungai Merpoh in the northeast region). The question is, why does the northeast region often face algae growth compared to other areas. The inlet region, the major water source, is an economic area due to livestock farming, which has been linked to water contamination. The study's outcome [10] has shown that cattle economic activities around the inlet impact water quality with high chlorophyll concentrations and total phosphorus. The Trophic Level Index is a measure of dam water quality, indicating its biological condition or productivity. A higher trophic index indicates poorer lake water quality.

Normalized Difference Vegetation Index (NDVI) is known to monitor vegetation health and land cover. In fact, healthy vegetation generally exhibits higher NDVI, while unhealthy or stressed vegetation may result in lower NDVI values. Healthy vegetation presents the amount of fertilizer it receives.

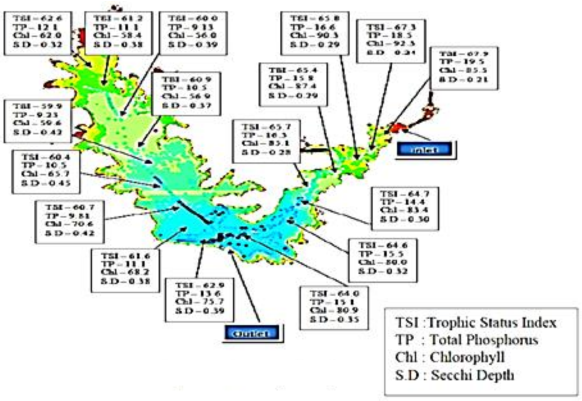

Figure 1. Water Quality parameters testing at different area around Sembrong dam [10]

Using this information, the area with a higher value of NDVI has a higher concentration of agriculture nutrient (fertilizer), which is possible for becoming a contaminant contributing to eutrophication. However, it should be evaluated based on contribution to land-used classification (how big the area for each type of activity in one particular land-used). On the other hand, NDVI is known to be used for monitoring the land use land cover (LULC) [11]. Contaminants could be transported via soil erosion to water bodies during precipitation events.

From this fact, NDVI can help monitor these changes by identifying areas of reduced vegetation cover, potentially indicating soil erosion via the reflectance values of two different spectral bands, usually the near-infrared (NIR) and red electromagnetic spectrum bands [12]. NDVI values range from -1 to +1. A high value of land cover presents higher vegetation with less soil erosion. In contrast, the low value of land cover presenting lower vegetation, possibly due to soil erosion during precipitation events, is high [13].

An aerial mapping approach on a catchment area of the reservoir was utilized to identify potential hotspots that are responsible for the deteriorating watershed water quality. It discusses the accuracy and limitations of different DEM generation methods for flood simulation. It highlights the benefits of using a 3D hydrodynamic model coupled with high-resolution topographic data obtained through digital aerial photogrammetry [14]. The paper also explores using Sentinel-2 imagery for catchment analysis, including automatically mapping lakes surface water using deep learning techniques [15]. Additionally, it examines the integration of NDVI and land use with runoff analysis to understand the impacts of soil and water conservation programs on vegetation regeneration and runoff patterns [16]. According to [17], the paper discusses the atmospheric deposition pathways for pollutant transport to water bodies, such as dams, and the importance of understanding the dynamics, sources, and ecological effects of pollutants like chlorinated pesticides, organic phosphorus, and organic pollutants as shown in Figure 2. It also highlights the significance of assessing groundwater infiltration pathways using remote sensing, GIS, and water pollution indices to identify suitable sites for groundwater recharge, manage heavy metal pollution, and ensure the quality and sustainability of water resources [18][19].

This study revolves around the challenges associated with surface runoff and water resource management at Sembrong Dam.

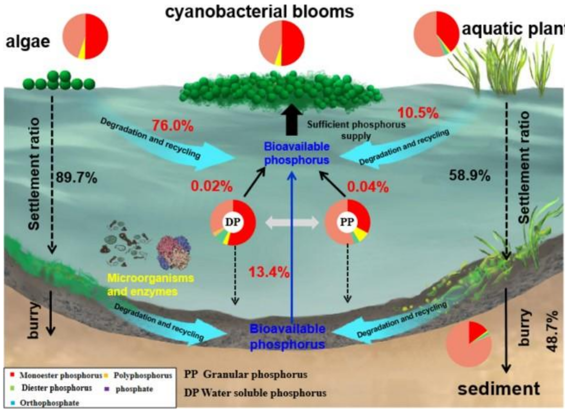

Figure 2. The role of agricultural nutrients (Phosphorus) in contributing to the onset of algal bloom incidents in lakes and the associated cyclic processes [20]

There is limited knowledge about the runoff patterns and their potential effects on dam operation. This lack of understanding hinders accurate analysis and management of runoff. The absence of a detailed runoff map and DEM further complicates the runoff analysis and management. The absence of a detailed runoff map and digital elevation model further complicates the process. The study aims to produce a catchment area map with a digital elevation model and analyze transit pathways that may cause water degradation to address these issues. Data acquisition through surveys, measurements, and Sentinel-2 imagery is used to analyze surface water patterns and their impacts on the dam's water quality. The methodology integrates techniques such as NDVI analysis, contour mapping, DEM generation, watershed analysis, and land use mapping. The research aims to produce the catchment area map with satellite imagery and to define the transit pathway that potentially causes water degradation of the Sembrong Dam.

METHOD

This methodology provides a comprehensive approach to investigating water pollution in Sembrong Lake. It combines site investigation, data collection, satellite image processing, and spatial analysis techniques to understand the factors that contribute to water degradation. The methodology is framed based on a provided flowchart outlining three key phases, as shown in Figure 3. In Phase 1, a preliminary survey, site investigation, fieldwork study, and data collection are conducted to gather comprehensive data on water conditions and sources of pollution. Phase 2 focuses on achieving Objective 1 by processing Sentinel-2 imagery using QGIS to generate a DEM, contour lines, watershed boundaries, and NDVI. Additionally, Phase 2 includes Objective 2, which involves analyzing transit pathways that potentially cause water degradation by overlapping contour lines, watershed boundaries, NDVI values, land use polygons, and observed algae locations. The study aims to use this approach to create a catchment area map with a digital elevation model of the land use region around Sembrong Dam and assess transit pathways that may be causing water deterioration at Sembrong Dam. The outcome is important discoveries that lead to a better understanding of water deterioration in the Sembrong Dam Lake.

Processing

Satellite image analysis is crucial for understanding water pollution and land use patterns. Data preprocessing is the first step, ensuring high-quality data from the Copernicus Sentinel-2 satellite. The focus then shifts to mapping water pollution, generating a DEM to identify water concentration areas and vulnerable points. Contour mapping visualizes height differences and water flow directions.

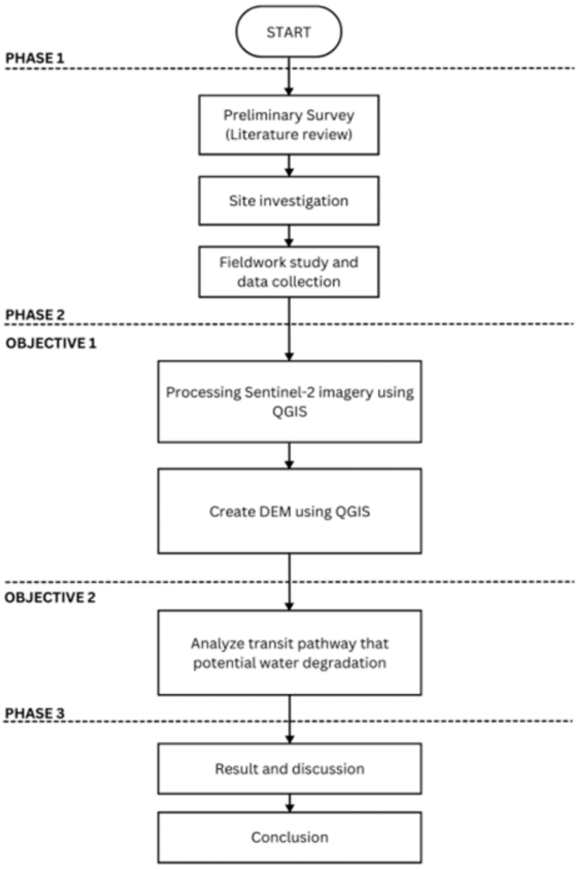

Figure 3. Research flowchart

A watershed is created to identify main flow channels and tributaries. NDVI assesses green plant concentrations and provides insights into potential water pollution related to human activities.

Furthermore, a pathway transit analysis is conducted to identify potential transit pathways to the Sembrong Dam that cause water degradation. This analysis involves spatial analysis using GPS coordinates, topographic maps, and land use data. By comparing known water degradation sources with the area around the dam, overlapping patterns can be identified in order to indicate potential transit routes. Land use data helps identify areas that have the potential to cause water degradation, while topographic data assists in understanding water flow directions. NDVI analysis aids in identifying areas with low or disturbed vegetation that could contribute to water pollution.

RESULTS AND DISCUSSION

The results reveal that the region around the inlet where cattle economic activities had an impact on water quality with high concentrations of phosphorus and ammonia nitrogen [10]. This proves that eutrophication will continue to increase in the following decades as a result of excessive nutrients entering the watershed from human activities [21]. The study is conducted at Sembrong Dam in Air Hitam, Johor, with coordinates 1°59'52"N 103°10'51"E. The Sembrong Dam covers an area of approximately 1,200 hectares. The methodology involves a comprehensive assessment of surface runoff mapping for water quality at Sembrong Dam. In Phase 1 of the fieldwork study flow chart, the study begins with a thorough site investigation where researchers, accompanied by representatives from Jabatan Pengaliran dan Saliran (JPS), observe the dam's physical characteristics, water quality and surrounding environment shown in Figure 4.

The subsequent phase focuses on investigating specific sites within the study area that have experienced water pollution and examining the surrounding areas. This reservoir appears prone to eutrophication phenomena because of the profile and land used surrounding the dam itself. Deep lakes usually experience less eutrophication than shallow lakes. This is due to the fact that deep lakes have distinct water columns, dividing them into epilimnion, metalimnion, and hypolimnion, where nutrients settle, and thermal stratification prevents material exchange between layers.

Figure 4. Observed the dam's physical characteristics, water quality, and surrounding environment

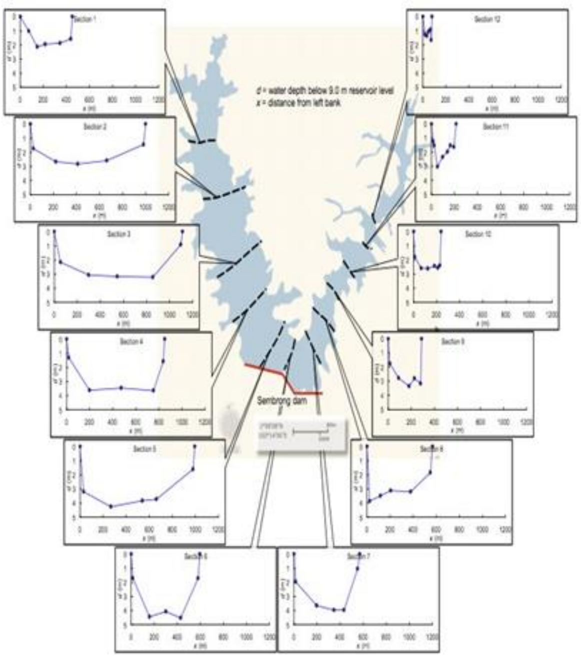

Figure 5. Water depth across Sembrong Dam [22]

Figure 5 shows the water depth of Sembrong Dam in both regions. The deepest level ever recorded for Sembrong Dam is approximately 9 m in depth [22]. Detailed observations and data acquisition are carried out to understand the conditions and factors associated with water pollution, including the analysis of land use and the identification of algae species, as shown in Figure 6. By combining these investigations, the research aims to comprehensively understand water pollution and its relationship with human activities in the Sembrong dam area.

(a) (b) (c)

Figure 6. (a) and (b) Algae at Sembrong lake banks and (c). Oil palm plantation of land use area

In the site investigation analysis section of the study, a site investigation was conducted to investigate the visual real-time condition of the reservoir's water quality. The presence of algae in the lake may be attributed to the nearby modern agriculture project and the proximity of UK Farm, which is known for animal husbandry and agriculture. Visual observations and captured images proved that the distribution of green algae along the lake banks, as shown in Figure 7. The location records for algae point 1 (1.97407256, 103.19116294) and algae point 2 (1.97512604, 103.19166619).

The presence of oil palm plantations in the surrounding area indicates a significant land use pattern. The growth of agricultural and forestry zones near watersheds resulted in contaminated reservoir's water. The results of the site observation concluded that almost around the dam area is surrounded by palm oil plantation activities, which are believed to be high levels usage ammonia, potassium, and phosphate, the major chemicals found in agricultural fertilizers and pesticides to cause water pollution [23]. This finding is supported by the results of data analysis from satellite images utilizing geospatial techniques such as DEM and NDVI analysis. NDVI values positive indicate healthy vegetation and low values indicate non-vegetated surfaces. It is particularly sensitive to changes in vegetation cover and health. NDVI values are directly related to the density and health of vegetation [24]. Healthy and dense vegetation typically has higher NDVI values, while sparse or stressed vegetation has lower values. In areas with significant soil cover and minimal vegetation, NDVI values will be lower. Soil erosion often leads to removing topsoil, exposing bare soil surfaces. Bare soil surfaces generally have lower NDVI values compared to vegetated areas.

Figure 7. (a). Algae location 1 and (b). Algae location 2

The DEM analysis generated precise DEM and contour mapping using satellite image processing techniques. The contour map visually represents elevation variations across the landscape, with different colours representing different elevation ranges. Water pollution could be identified based on elevation and topographical features by analyzing the DEM and contour mapping results. The Normalized Difference Vegetation Index (NDVI) analysis conducted as part of the satellite image processing analysis provides a comprehensive assessment of vegetation health and its relationship to water degradation in Sembrong Lake. By deriving NDVI values from satellite imagery, a detailed NDVI map with distinct legend categories was generated, as shown in Figure 8. The dark green areas indicate robust and healthy vegetation cover, while the medium dark green areas represent dense vegetation cover, contributing to a more sustainable water environment. Light green areas exhibit moderate vegetation cover but may be more susceptible to water pollution. Grey areas signify sparse or stressed vegetation, which could be attributed to various factors, including water pollution or environmental stressors, as shown in Figure 9. The absence of blue and dark blue colours suggests no areas lacking vegetation cover or severe water degradation. Analyzing the distribution of NDVI categories allows for identifying areas of concern and prioritizing further investigations. This analysis provides valuable insights into the spatial patterns of vegetation health and its potential relationship to water pollution, serving as a foundation for developing effective management strategies to mitigate water degradation and preserve the ecological integrity of Sembrong Lake.

Overall, the region surrounding the dam is covered with vegetation with an NDVI value of 0.8, with a small area of land having an NDVI of 0.2. The numbers obtained accurately define canopy reflectance, which assesses vegetative density and stress. High NDVI values could result from healthy plant growth due to adequate nutrients. A value of 0.8 displays very robust vegetation cover, indicating that the area is likely thriving and well-nourished. However, NDVI values in open regions with minimal plant cover range from 0.10-0.20, while for water bodies range from -1.0 - 0.0 [25].

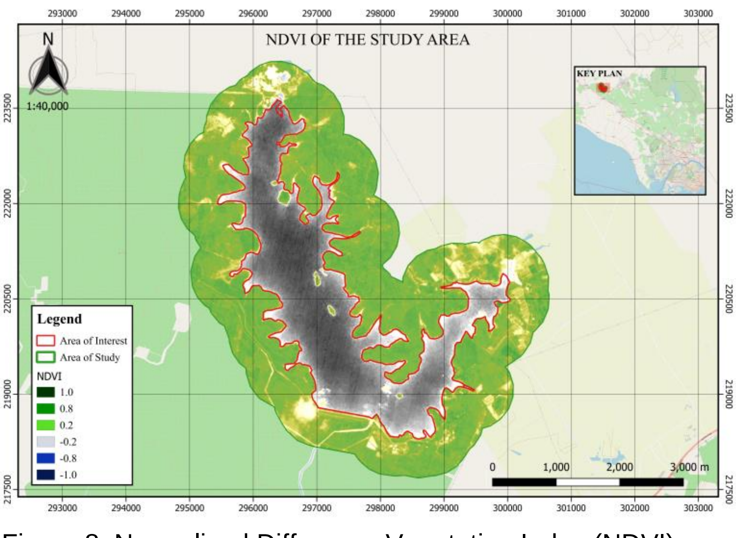

Figure 8. Normalized Difference Vegetation Index (NDVI) map

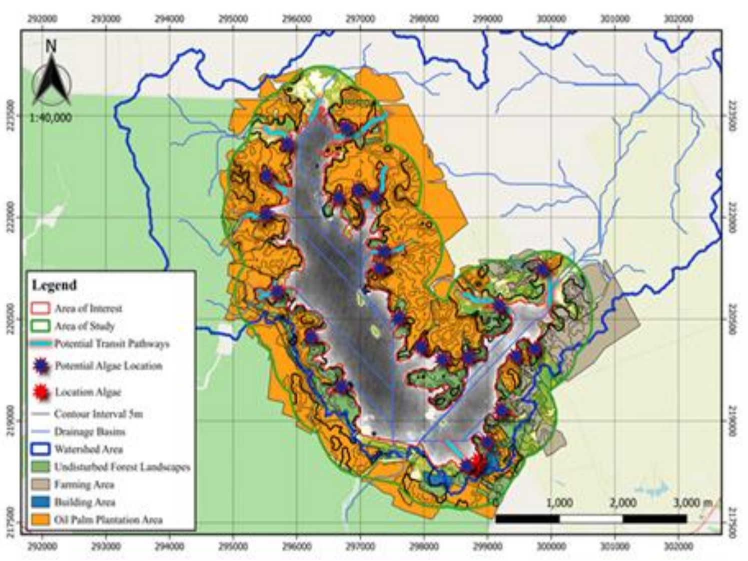

Figure 9. Potential algae location growth and potential transit pathway causing water degradation

This evidence shows NDVI is capable of distinguishing the vegetation cover from other objects on the ground. On the other hand, a study [26] revealed that NDVI can also be utilized as satellite monitoring based on the health of vegetation by detection of soil moisture content. Healthy vegetation typically requires adequate soil moisture. Changes in NDVI can suggest variations in soil moisture levels. High moisture levels due to overapplication of fertilizers may cause nutrient runoff into surrounding bodies of water, resulting in eutrophication and water quality concerns.

Shallow areas of lakes often experience more pollution than deeper areas. This is because shallow regions typically have higher levels of sunlight, which can promote algae growth. Sembrong dam in the North-East region experiences more pollution due to its narrow and shallow location, which can lead to stagnation and higher concentrations of pollutants. Site visits have shown that the North-East region often faces algae growth compared to other regions. The region's narrow geography and deep depth of up to 3m make it more susceptible to eutrophication than shallow lakes. The North-East region is also surrounded by various activities, including agriculture, residential, and livestock, which impact studies on pollution-causing activities. Therefore, it is crucial to address these issues to mitigate the negative effects of pollution on the environment.

The Watershed Analysis mapping conducted as part of the study is aimed to delineate and identify watershed boundaries using satellite imagery, DEM, and contour data. Figure 10 shows a watershed map and highlighted drainage basins in the watershed area. These drainage basins are susceptible to water degradation from land use areas, so applying any mitigation approach is crucial. Establish buffer zones along the shoreline to filter runoff before it reaches the lake. Regarding the result of the analysis, an area within the watershed area should be declared as a buffer zone. These areas might take in nutrients, preventing them from entering the water. For example, grasses and bushes may absorb excess nutrients (such as nitrogen and phosphorus) from runoff before they enter the lake. This minimizes the nutrient concentration that leads to algal blooms. Furthermore, vegetation could assist in minimizing erosion and trap sediments transported by runoff, reducing sediment and nutrient flow into the lake as a consequence of heavy rainfall. Implementing and maintaining buffer zones may enhance water quality and reduce the probability of eutrophication.

Understanding the LULC and water conditions with various tools could help assess the influence of pollution levels in nearby reservoirs. As populations increase, land use shifts from vegetation-covered areas to economic areas, causing top soil cover to be disturbed [27] This leads to sedimentation, causing eroded materials with pollutant substances to flow into reservoirs. Rainfall causes erosion through shear stress, affecting top soil detachment and slope gradient, making vegetation a significant factor in soil erosion rates [28]. Previous studies have been carried out on assessing water quality by direct measurement of water parameters.

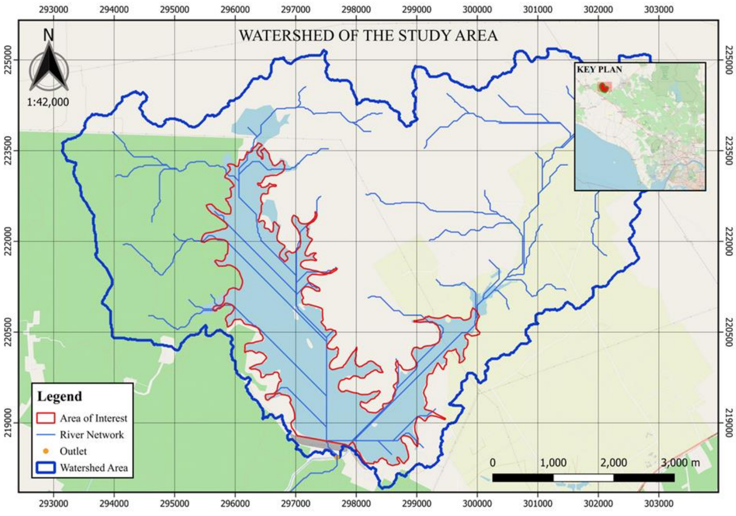

Figure 10. Watershed map and highlighted drainage basins in the watershed area

The status of water quality is visualized using the Trophic Status Index (TSI). It is known as a trophic level for assessing nutrient levels and biological productivity, making it easier to locate the hotspot for a mitigation approach based on the water quality condition in a reservoir. Analysis via remote sensing data has played a role in detecting potential water pollution sources in the land surrounding a reservoir.

Usage of DEM and DTM provides elevation data that can help analyze the landscape's slope and drainage patterns. This is crucial for understanding how water flows over the land and how pollutants might be transported to the reservoir. Besides, usage of NDVI has strong signal alterations in land use or land cover, such as increased agriculture or urbanization, which may contribute to runoff and pollution. By integrating remote sensing data and in-situ measurement, the spatial relationship between vegetation health and topography, identifying areas where poor land management practices might lead to water quality issues.

CONCLUSION

The study on the assessment of catchment area mapping at Sembrong Dam successfully produced a comprehensive catchment area map with a digital elevation model. The Sembrong Dam has a catchment area of approximately 130 km² and the sources of water sources supplied to the dam are from Sembrong's and Merpo's rivers, which flow from the north-west and east. Based on the results from the analysis of NDVI processing from satellite images from sentinel-2, it was found that the entire area around the catchment area has NDVI intensity that reflects vegetation density and plant health. The findings from the NDVI map and results from previous studies proved that the North-East region is slightly polluted compared to the North-West region, where there is less pollution in Sembrong Dam due to its geography and economic activities around the watershed area. This research improves on and validates a prior study that helps to understand LULC and water conditions by utilizing several approaches to analyze pollution levels in neighbouring reservoirs. Remote sensing data, DEM, DTM, and NDVI, may assist in detecting probable pollution sources and regions with poor land management practices, allowing for mitigation strategies. This research improves on and validates a prior study that helps to understand LULC and water conditions by utilizing several approaches to analyze pollution levels in neighbouring reservoirs. Remote sensing data, DEM, DTM, and NDVI, may assist in detecting probable pollution sources and regions with poor land management practices, allowing for mitigation strategies.

ACKNOWLEDGMENT

This research was supported by the Ministry of Higher Education (MOHE) through the Fundamental Research Grant Scheme (FRGS) K509 and Universiti Tun Hussein Onn Malaysia (UTHM) through the Postgraduate Research Grant (GPPS vot Q305). Support from the Centre of Applied Geomatics and Disaster Prevention (CAGeD) is gratefully acknowledged.

REFERENCES

[1] P. V. Caldwell et al., “Forested watersheds provide the highest water quality among all land cover types, but the benefit of this ecosystem service depends on landscape context,” *Science of the Total Environment*,

vol. 882, December 2022, 2023, doi: 10.1016/j.scitotenv.2023.163550.

[2] S. Cosgrove, and P. Jarvis, “Application of activated carbon fabric for the removal of a recalcitrant pesticide from agricultural runoff,” *Science of the Total Environment*, vol. 815, 2022, doi: 10.1016/j.scitotenv. 2021.152626.

[3] J. Tian *et al.*, “Biochar application under low phosphorus input promotes soil organic phosphorus mineralization by shifting bacterial phoD gene community composition,” *Science of the Total Environment*, vol. 779, p. 146556, 2021, doi: 10.1016/j.scitotenv.2021.146556.

[4] D. Zhaxi and C. Jing, “Understanding the indirect impacts of urbanization on vegetation growth using the Continuum of Urbanity framework,” *Science of the Total Environment*, vol. 899, p. 165693, 2023, doi: 10.1016/j.scitotenv.2023.165693.

[5] X. Zhang *et al.*, “Impact of Land Use Changes on the Surface Runoff and Nutrient Load in the Three Gorges Reservoir Area, China,” *Sustainability*, vol. 14, p. 2023, 2022, doi: 10.3390/su14042023.

[6] Z. Ren and Z. Li, “Effects of Extreme Precipitation on Runoff and Sediment Yield in the Middle Reaches of the Yellow River,” *Atmosphere (Basel)*, vol. 14, no. 9, 2023, doi: 10.3390/atmos14091415.

[7] H. I. Lin and P. T. Liu, “Status of Food Security in East and Southeast Asia and Challenges of Climate Change,” *Climate*, vol. 10, no. 3, 2022, doi: 10.3390/cli10030040.

[8] J. S. Kayode *et al.*, “Hydrogeophysical modeling of the groundwater aquifer units under climate variability in parts of Peninsular Malaysia: A case study of the climate-water nexus approach to sustainability,” *Heliyon*, vol. 9, no. 3, 2023, doi: 10.1016/j.heliyon.2023.e13710.

[9] Z. Wang and X. Fu, “Quantifying the impact of climate change and anthropogenic activities on runoff and sediment load reduction in a typical Loess Plateau watershed,” *Journal of Hydrology: Regional Studies*, vol. 39, no. July 2021, 2022, doi: 10.1016/j.ejrh.2022.100992.

[10] S. I. N. S. Hashim and S. A. M. Tajuddin, “Water Quality and Trophic Status Study in Sembrong Reservoir during Monsoon Season,” *IOP Conference Series: Earth and Environmental Science*, vol. 140, no. 1, 2018, doi: 10.1088/1755-1315/140/1/012079.

[11] W. Ullah *et al.*, “Analysis of the relationship among land surface temperature (LST), land use land cover (LULC), and normalized difference vegetation index (NDVI) with topographic elements in the lower Himalayan region,” *Heliyon*, vol. 9, no. 2, 2023, doi: 10.1016/j.heliyon.2023.e13322.

[12] G. Winarso and J. Supriatna, “Comparison of Mangrove Index (MI) and Normalized Difference Vegetation Index (NDVI) for the detection of degraded mangroves in Alas Purwo Banyuwangi and Segara Anakan Cilacap, Indonesia,” *Ecological Engineering*, vol. 197, no. August 2021, 2023, doi: 10.1016/j.ecoleng.2023.107119.

[13] Z. jian Xie and W. Qi, “The global progress on the non-point source pollution research from 2012 to 2021: a bibliometric analysis,” *Environmental Sciences Europe*, vol. 34, no. 1, 2022, doi: 10.1186/s12302-022-00699-9.

[14] Y. Rong and P. Feng, “Three-dimensional urban flood inundation simulation based on digital aerial photogrammetry,” *Journal of Hydrology (Amsterdam)*, vol. 584, p. 124308, 2019, doi: 10.1016/j.jhydrol.2019.124308.

[15] Y. Qin and P. Lu, “A fully automatic framework for sub-pixel mapping of thermokarst lakes using Sentinel-2 images,” *Science of Remote Sensing*, vol. 8, no. June, 2023, doi: 10.1016/j.srs.2023.100111.

[16] A. Menasria and H. Habaieb, “Diachronic Study of Land Cover of the Medjerda Watershed and Estimation of RUSLE-C Factor Using NDVI-Based Equation, Remote Sensing, and GIS,” *Journal of the Indian Society of Remote Sensing*, vol. 50, 2022, doi: 10.1007/s12524-021-01472-w.

[17] C. Schwanen and J. Schwarzbauer, “Dynamic Transport and Distribution of Organic Pollutants in Water and Sediments of the Rur River,” *Water Air Soil Pollut*, vol. 235, 2023, doi: 10.1007/s11270-023-06786-8.

[18] S. Baghel and A. Elbeltagi, “Delineation of suitable sites for groundwater recharge based on groundwater potential with RS, GIS, and AHP approach for Mand catchment of Mahanadi Basin,” *Scientific Reports*, vol. 13, no. 1, pp. 1–23, 2023, doi: 10.1038/s41598-023-36897-5.

[19] M. Rahman and Z. Aktar, “Heavy metal pollution assessment in the groundwater of the Meghna Ghat industrial area, Bangladesh, by using water pollution indices approach,” *Applied Water Science*, vol. 10, 2020, doi: 10.1007/s13201-020-01266-4.

[20] W. Feng et al., "Chemical composition, sources, and ecological effect of organic phosphorus in water ecosystems: a review Graphical Abstract," *Carbon Research*, vol. 2, p. 12, 2024, doi: 10.1007/s44246-023-00038-4.

[21] A. Singh *et al.*, "Anaerobic digestion as a tool to manage eutrophication and associated greenhouse gas emission," *Science of the Total Environment*, vol. 861, no. November 2022, 2023, doi: 10.1016/j.scitotenv.2022.160722.

[22] H. Awang and Mohd. Z. Mohd. Hatta, "Hydrology Properties and Water Quality Assessment of the Sembrong Dam, Johor, Malaysia," *Procedia - Social and Behavioral Sciences*, vol. 195, pp. 2868–2873, 2015, doi: 10.1016/j.sbspro.2015.06.40.

[23] Y. Zhang and P. Pellikka, "Total Phosphorus and Nitrogen Dynamics and Influencing Factors in Dongting Lake Using Landsat Data," *Remote Sensing (Basel)*, vol. 14, no. 22, 2022, doi: 10.3390/rs14225648.

[24] G. Winarso and J. Supriatna, "Comparison of Mangrove Index (MI) and Normalized Difference Vegetation Index (NDVI) for the detection of degraded mangroves in Alas Purwo Banyuwangi and Segara Anakan Cilacap, Indonesia," *Ecological Engineering*, vol. 197, no. September, 2023, doi: 10.1016/j.ecoleng.2023.107119.

[25] W. Chouari, "Assessment of vegetation cover changes and the contributing factors in the Al-Ahsa Oasis using Normalized Difference Vegetation Index (NDVI)," *Regional Sustainability*, vol. 5, no. 1, pp. 1–12, 2024, doi: 10.1016/j.regsus.2024.03.005.

[26] M. Kumar *et al.*, "Detection of water deficit conditions in different soils by comparative analysis of standard precipitation index and normalized difference vegetation index," *Heliyon*, vol. 9, p. e15093, 2023, doi: 10.1016/j.heliyon.2023.e15093.

[27] Juliastuti and T. K. Wihartono, "The assessment of drainage performance in the residential area using SWMM," *Sinergi (Indonesia)*, vol. 27, no. 2, pp. 281–288, 2023, doi: 10.22441/sinergi.2023.2.016.

[28] F. Asferizal and H. R. Hasibuan, "Drainage system analysis using Storm Water Management Model (SWMM) in flood mitigation efforts in the valley area," *Sinergi (Indonesia)*, vol. 28, no. 3, pp. 585–594, 2024, doi: 10.22441/sinergi.2024.3.014.