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Integrated River Health Assessment in the Sungai Muda Basin Using the River Health Index (RHI): Comparison between the 2023 Baseline and the 2025-2026 Assessment

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ABSTRACT

River health assessment is essential for sustainable water resource management because river ecosystems are influenced by physicochemical, biological, physical habitat and anthropogenic factors. Conventional monitoring in Malaysia primarily relies on the Water Quality Index (WQI), which evaluates only physicochemical water quality and may not adequately represent the overall ecological condition of a river. Therefore, this study applied the River Health Index (RHI) to evaluate the health status of the Sungai Muda Basin and compare the current condition with the 2023 baseline assessment. Eight monitoring stations distributed from the upstream to downstream sections of the basin were assessed during the 2025–2026 dry season. The assessment integrated four RHI sub-indices, namely chemical, biological, physical habitat and sociological components. The chemical assessment employed the Department of Environment Water Quality Index (WQI), while biological assessment utilized the Biological Monitoring Working Party (BMWP) scoring system and Biological Water Quality Index (BWQI). Physical habitat and sociological assessments were conducted according to the Department of Irrigation and Drainage River Health Index guideline. The results demonstrated that all monitoring stations achieved Category A (Very Healthy), with the mean RHI increasing from 75.39 during the 2023 baseline assessment to 83.98 in the 2025–2026 assessment. The mean WQI also increased from 78.13 to 88.17, indicating substantial improvement in physicochemical water quality. Correlation analysis revealed a very strong positive relationship between WQI and RHI ($R^2 = 0.9943$), whereas weak relationships were observed between BWQI and RHI ($R^2 = 0.0115$) and between WQI and BWQI ($R^2 = 0.0244$). These findings indicate that biological communities respond to additional ecological factors beyond water chemistry alone. The River Health Index therefore provides a more comprehensive framework for evaluating river ecosystem health and supports sustainable river monitoring and management in Malaysia.

INTRODUCTION

Rivers are fundamental freshwater resources that provide a wide range of ecosystem services, including domestic water supply, agricultural irrigation, industrial use, flood regulation, and habitat for aquatic organisms[1]. The health of river ecosystems is increasingly threatened by rapid urbanisation, agricultural expansion, industrial development, and other anthropogenic activities, which alter water quality and ecological integrity. Consequently, continuous river monitoring is essential to support sustainable water resource management and ensure the long-term conservation of freshwater ecosystems[2].

In Malaysia, river water quality is commonly assessed using the Department of Environment (DOE) Water Quality Index (WQI), which integrates six physicochemical parameters, namely dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), suspended solids (SS), and pH [3]. The WQI has been widely adopted because it provides a simple and effective approach for classifying river water quality and supporting regulatory decision-making[4]. However, the WQI primarily reflects the physicochemical condition of a river during the sampling period and does not adequately represent the ecological condition of the river ecosystem. Biological communities, habitat quality, and anthropogenic disturbances are not incorporated into the conventional WQI assessment, limiting its ability to describe overall river health[5].

To overcome these limitations, the River Health Index (RHI) has been developed as an integrated assessment framework that combines chemical, biological, physical habitat, and sociological components into a single river health evaluation. Unlike conventional water quality assessment, the RHI considers both environmental conditions and ecological responses, providing a more comprehensive understanding of river ecosystem health. The biological component utilises benthic macroinvertebrates as bioindicators because these organisms respond to long-term environmental changes and pollution stress. Meanwhile, physical habitat and sociological assessments evaluate channel conditions, riparian integrity, land use, and human interactions with the river, enabling a holistic assessment of ecosystem condition[6].

The Sungai Muda Basin is one of the most significant river systems in northern Peninsular Malaysia, supplying raw water for domestic consumption, agriculture, and industrial activities in Kedah and Penang. Despite its strategic importance, increasing land-use changes and human activities within the basin continue to exert pressure on river health. Previous assessments have primarily focused on physicochemical water quality, while comprehensive evaluations integrating biological, physical, and sociological components remain limited. Furthermore, comparisons between historical and recent river health conditions are rarely reported, making it difficult to evaluate the effectiveness of river management initiatives over time[7].

Therefore, this study applied the River Health Index (RHI) to evaluate the current river health status of the Sungai Muda Basin and compare the findings with the 2023 baseline assessment. The study also examined the relationships among the Water Quality Index (WQI), Biological Water Quality Index (BWQI), and River Health Index (RHI) to determine whether improvements in physicochemical water quality were accompanied by corresponding improvements in ecological condition. The findings provide valuable information for river management authorities by demonstrating the advantages of integrated river health assessment over conventional physicochemical monitoring alone[8], [9].

RESEARCH METHODS

This study was conducted in the Sungai Muda Basin, located in the northern region of Peninsular Malaysia, covering parts of Kedah and Penang. The basin is one of the country's major water resources, supplying water for domestic consumption, agriculture, and industrial activities. Eight monitoring stations (M1, M2, M2A, M2B, M3, M3A, M4, and M5) were selected to represent the upstream, midstream, and downstream sections of the river. Field sampling was carried out during the 2025–2026 dry season to minimise the influence of rainfall on water quality. Baseline data collected during the 2023 River Health Index (RHI) assessment by the River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, were used for comparison with the present study. Figure 1 illustrates the location of the study area and the monitoring stations[10].

Water quality was assessed using six physicochemical parameters recommended by the Department of Environment (DOE) Malaysia, namely dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), ammoniacal nitrogen (NH_3-N), and pH. Grab water samples were collected at each monitoring station following the Standard Methods for the Examination of Water and Wastewater. In-situ measurements of DO and pH were performed using a calibrated YSI multiparameter probe, whereas BOD, COD, SS, and NH_3-N were analysed in the Environmental Engineering Laboratory, Universiti Sains Malaysia. The Water Quality Index (WQI) was subsequently calculated using the DOE Malaysia equation, and the water quality status was classified according to the National Water Quality Standards (NWQS)[11].

The biological assessment was conducted using benthic macroinvertebrates as indicators of river ecosystem health. Samples were collected using a 500 μm mesh dip net through kick-sampling and sweep-sampling techniques at all monitoring stations. The collected specimens were preserved in 70% ethanol and identified to the family level using standard taxonomic identification keys. The Biological Monitoring Working Party (BMWP) scoring system was employed to determine the Biological Water Quality Index (BWQI), which represents the biological component of river health assessment[12].

The overall river condition was evaluated using the River Health Index (RHI) developed by the Department of Irrigation and Drainage (DID) Malaysia. The RHI integrates four assessment components comprising chemical, biological, physical habitat, and sociological sub-indices. The chemical component was represented by the WQI, while the biological component was represented by the BWQI. Physical habitat assessment involved field observations of channel morphology, substrate composition, riparian vegetation, streamflow characteristics, and visible anthropogenic disturbances. The sociological assessment considered surrounding land use and stakeholder engagement based on the DID River Health Index guideline[13]. The final RHI score was calculated by combining the weighted scores of the four sub-indices, with weightages of 30% for chemical, 27% for physical habitat, 25% for biological, and 18% for sociological components. The calculated RHI values were then classified into Category A (Very Healthy), Category B (Moderately Healthy), Category C (Poor), and Category D (Very Poor).

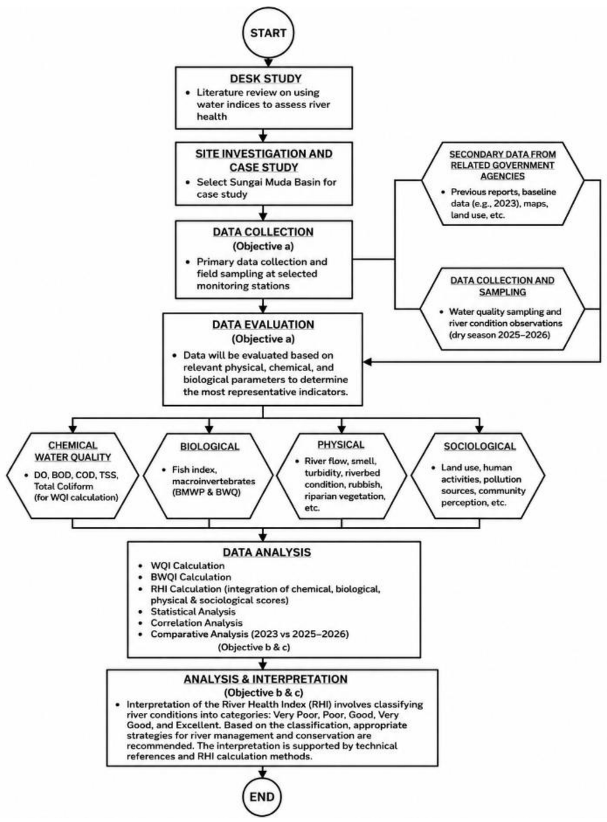

Figure 1. Overall research framework adopted in this study

RESULTS AND DISCUSSION

1. Comparison of Water Quality Index (WQI)

The Water Quality Index (WQI) demonstrated a clear improvement between the 2023 baseline assessment and the 2025–2026 monitoring period (Figure 2). During the 2025–2026 assessment, all eight monitoring stations recorded WQI values within Class II, with values ranging from 84.05 to 90.64 and an overall mean of 88.17. In comparison, the 2023 baseline assessment recorded a lower mean WQI of 78.13, with several stations approaching Class III water quality. The improvement indicates a general enhancement in physicochemical water quality throughout the Sungai Muda Basin.

The greatest improvement was observed at Station M2B, where the WQI increased from 71.00 in 2023 to 89.18 in 2025–2026. Similar improvements were recorded at Stations M1, M2, and M4, all of which shifted from lower Class II or Class III conditions to stable Class II status. These improvements were primarily associated with reductions in suspended solids (SS), biochemical oxygen demand (BOD), and ammoniacal nitrogen (NH_3-N), suggesting lower pollutant loading and improved water quality conditions during the assessment period[14].

Although Station M5 exhibited a slight decrease in WQI compared with the baseline assessment, the difference was minimal and the station remained within Class II. Overall, the WQI results indicate a substantial improvement in physicochemical water quality across the Sungai Muda Basin.

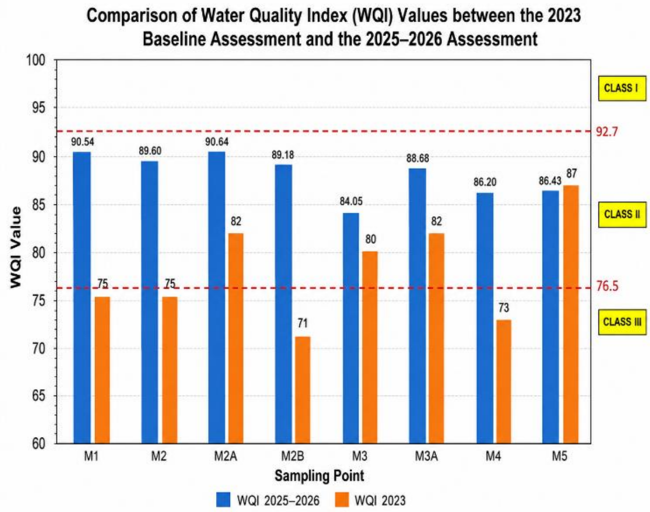

Figure 2. Comparison of WQI values between 2023 and 2025–2026

2. Comparison of Biological Water Quality Index (BWQI)

In contrast to the WQI results, the Biological Water Quality Index (BWQI) exhibited a more variable spatial pattern (Figure 3). The highest BWQI value during the 2025–2026 assessment was recorded at Station M2A (8.80), indicating favourable ecological conditions and greater macroinvertebrate diversity. However, several monitoring stations, particularly M2B, M3A, and M4, recorded comparatively low BWQI values despite improvements in physicochemical water quality.

This difference demonstrates that biological communities often respond more slowly than chemical parameters following environmental improvement. While water chemistry may recover rapidly due to reduced pollutant inputs or favourable hydrological conditions, recolonisation by pollution-sensitive macroinvertebrate taxa requires suitable habitat conditions and sufficient recovery time. Consequently, BWQI provides valuable information regarding the long-term ecological condition of the river, complementing conventional physicochemical assessments.

The observed variation between WQI and BWQI further emphasises the importance of incorporating biological indicators into river health assessments, as reliance on chemical parameters alone may overestimate ecosystem recovery.

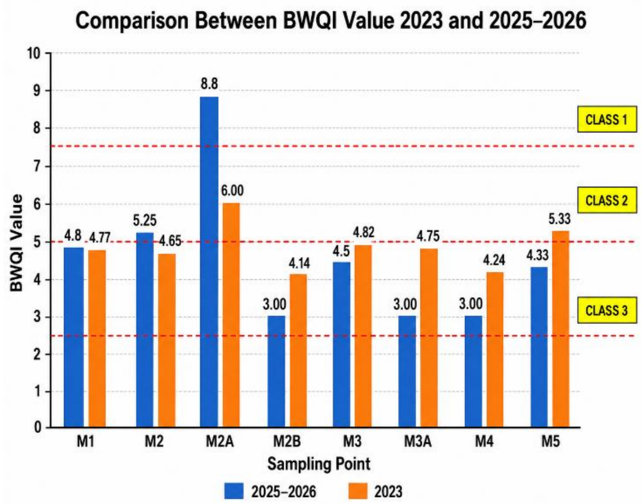

Figure 3. Comparison of BWQI values between 2023 and 2025–2026

3. River Health Index (RHI) Assessment

The River Health Index (RHI) demonstrated an overall improvement in the ecological condition of the Sungai Muda Basin between the 2023 baseline assessment and the 2025–2026 monitoring period (Figure 4). The mean RHI increased from 75.39 in 2023 to 83.98 in 2025–2026, indicating an improvement of approximately 8.59 index points. More importantly, all eight monitoring stations were classified as Category A (Very Healthy) during the latest assessment, reflecting an overall enhancement in river ecosystem health.

The improvement in RHI was primarily influenced by higher chemical sub-index scores, which resulted from better physicochemical water quality, particularly the reductions in suspended solids (SS), biochemical oxygen demand (BOD), and ammoniacal nitrogen (NH_3-N). Improvements in physical habitat conditions and favourable sociological assessments also contributed to the higher RHI scores across the monitoring stations.

Although biological recovery remained inconsistent at several locations, the integrated assessment framework enabled the RHI to capture the combined influence of chemical, biological, physical habitat, and sociological conditions. This demonstrates the advantage of the RHI over conventional water quality assessment, as river health is evaluated from multiple ecological perspectives rather than relying solely on physicochemical parameters.

The largest increase in RHI was observed at Station M2B, which recorded substantial improvement compared with the 2023 assessment. This station also exhibited the greatest increase in WQI, indicating that improvements in physicochemical conditions contributed significantly to the overall enhancement of river health. Nevertheless, the relatively low BWQI recorded at this station suggests that biological communities require a longer period to recover following improvements in water quality.

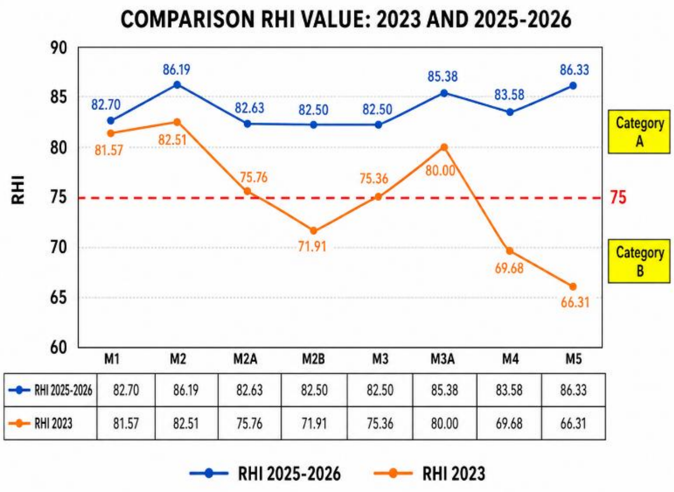

Figure 4. Comparison of River Health Index (RHI) values between the 2023 baseline and the 2025–2026 assessment

4. Relationship between WQI, BWQI and RHI

Correlation analysis was performed to evaluate the relationships among the Water Quality Index (WQI), Biological Water Quality Index (BWQI), and River Health Index (RHI) (Figure 5).

A very strong positive relationship was observed between WQI and RHI (R^2 = 0.9943), indicating that improvements in physicochemical water quality strongly influenced the overall River Health Index. This finding is expected because the chemical component contributes 30% of the total RHI score and reflects the immediate physicochemical condition of the river. Consequently, stations with higher WQI values generally exhibited higher RHI scores.

Conversely, BWQI showed only a weak relationship with RHI (R^2 = 0.0115). This result suggests that biological communities respond differently from physicochemical parameters because macroinvertebrates integrate long-term environmental conditions rather than short-term changes in water quality. Biological recovery is influenced not only by water chemistry but also by habitat complexity, substrate composition, riparian vegetation, hydrological conditions, and recolonisation processes[15]. Therefore, improvements in water quality alone do not necessarily produce immediate improvements in biological integrity. Similarly, the relationship between WQI and BWQI was weak (R^2 = 0.0244), further demonstrating that physicochemical water quality does not always accurately represent ecological health. Stations with relatively high WQI values may still support limited macroinvertebrate diversity if habitat conditions remain unsuitable or ecological recovery has not yet occurred[16].

These findings highlight the importance of adopting integrated assessment frameworks such as the River Health Index. While WQI remains an effective indicator for monitoring chemical water quality, incorporating biological, physical habitat, and sociological components provides a more realistic representation of river ecosystem health and supports more informed river management decisions.

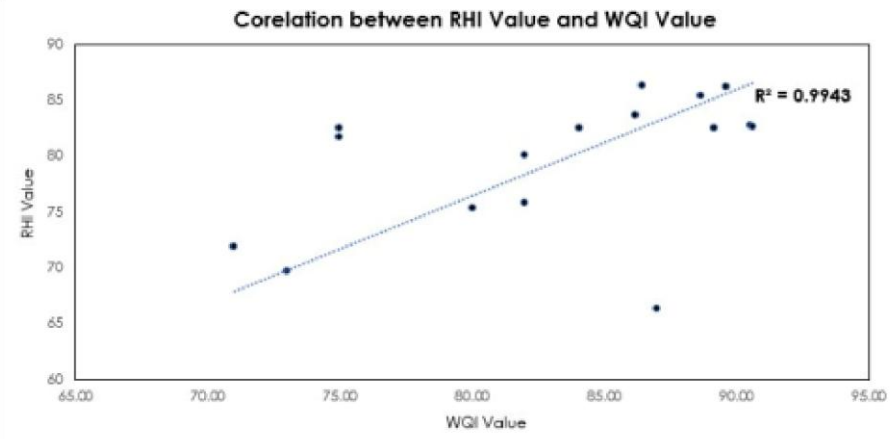

Figure 5. Correlation between WQI and RHI

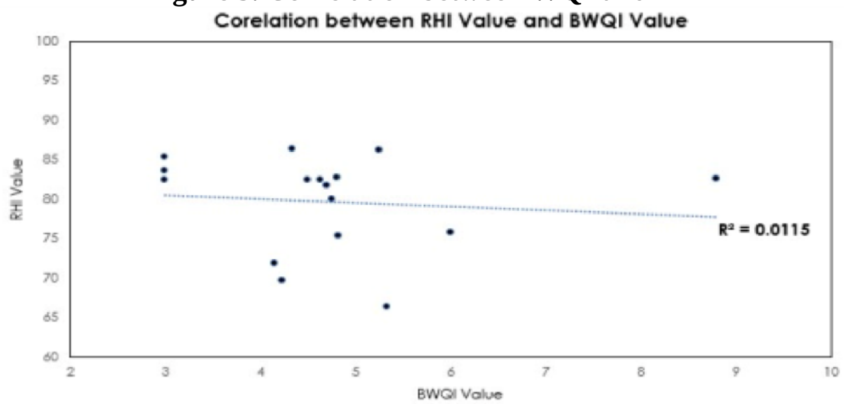

Figure 6. Correlation between BWQI and RHI

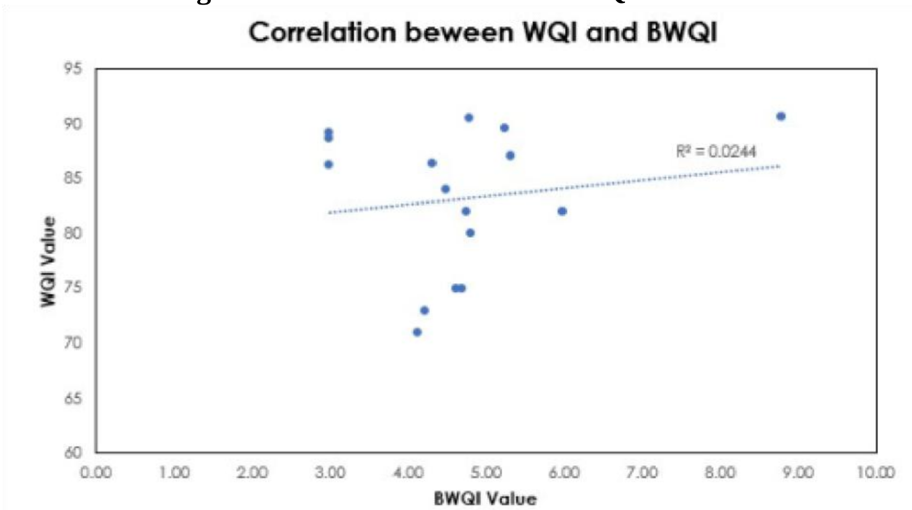

Figure 7. Correlation between WQI and BWQI.)

CONCLUSION

This study evaluated the river health status of the Sungai Muda Basin using the River Health Index (RHI) and compared the findings with the 2023 baseline assessment. The results demonstrated a substantial improvement in overall river condition during the 2025–2026 monitoring period, with the average RHI increasing from 75.39 to 83.98 and all monitoring stations achieving Category A (Very Healthy) status. The Water Quality Index (WQI) also improved considerably, indicating enhanced physicochemical water quality throughout the basin.

Despite these improvements, the Biological Water Quality Index (BWQI) exhibited greater spatial variability and weaker correlations with both WQI and RHI, suggesting that biological communities respond to a broader range of ecological factors beyond water chemistry alone. This finding emphasises that improvements in physicochemical water quality do not necessarily correspond to immediate biological recovery.

Overall, the River Health Index proved to be a comprehensive assessment framework by integrating chemical, biological, physical habitat, and sociological components into a single evaluation. Compared with conventional WQI assessment, the RHI provides a more holistic understanding of river ecosystem condition and offers valuable scientific information to support sustainable river monitoring, restoration planning, and water resource management in Malaysia.

REFERENCES

[1] J. D. Allan, “Landscapes and riverscapes: The influence of land use on stream ecosystems,” *Annu. Rev. Ecol. Evol. Syst.*, vol. 35, no. Volume 35, 2004, pp. 257–284, Dec. 2004, doi: 10.1146/ANNUREV.ECOLSYS.35.120202.110122/CITE/REFWORKS.

[2] S. C. Jähnig *et al.*, “Ecosystem Services of River Systems – Irreplaceable, Undervalued, and at Risk,” *Encyclopedia of Inland Waters, Second Edition*, vol. 2, pp. 424–435, Jan. 2022, doi: 10.1016/B978-0-12-819166-8.00129-8.

[3] I. Naubi, N. H. Zardari, S. M. Shirazi, N. F. B. Ibrahim, and L. Baloo, “Effectiveness of Water Quality Index for Monitoring Malaysian River Water Quality,” *Pol. J. Environ. Stud.*, vol. 25, no. 1, pp. 231–239, Jan. 2016, doi: 10.15244/PJOES/60109.

[4] Y. J. Wong, Y. Shimizu, K. He, and N. M. Nik Sulaiman, “Comparison among different ASEAN water quality indices for the assessment of the spatial variation of surface water quality in the Selangor river basin, Malaysia,” *Environmental Monitoring and Assessment 2020 192:10*, vol. 192, no. 10, pp. 644-, Sep. 2020, doi: 10.1007/S10661-020-08543-4.

[5] N. Jargal, J. E. Kim, B. Ariunbold, and K. G. An, “Ecological river health assessments, based on fish ordination analysis of ecological indicator entities and the biological integrity metrics, responding to the chemical water pollution,” *Environmental Science and Pollution Research 2024 31:19*, vol. 31, no. 19, pp. 28306–28320, Mar. 2024, doi: 10.1007/S11356-024-32862-5.

[6] S. Shaharuddin *et al.*, “River Health Index: A Review on Current Assessment Practice in Malaysia Towards a Holistic Evaluation of River Health,” *Journal of Water Resources Management*, vol. 3, no. 2, Dec. 2025, Accessed: Aug. 11, 2026. [Online]. Available: https://journal.water.gov.my/index.php/jowrm/article/view/38

[7] “(PDF) COMPREHENSIVE WATER RESOURCES ASSESSMENT CONSIDERING CLIMATE CHANGE FOR THE MUDA RIVER BASIN, KEDAH, MALAYSIA.” Accessed: Aug. 11, 2026. [Online]. Available: https://www.researchgate.net/publication/330751147_COMPREHENSIVE_WATER_RESOURCES_ASSESSMENT_CONSIDERING_CLIMATE_CHANGE_FOR_THE_MUDA_RIVER_BASIN_KEDAH_MALAYSIA

[8] “(PDF) River Health Index: A Review on Current Assessment Practice in Malaysia Towards a Holistic Evaluation of River Health.” Accessed: Aug. 11, 2026. [Online]. Available: https://www.researchgate.net/publication/399218948_River_Health_Index_A_Review_on_Current_Assessment_Practice_in_Malaysia_Towards_a_Holistic_Evaluation_of_River_Health

[9] Y. J. Wong, Y. Shimizu, K. He, and N. M. Nik Sulaiman, “Comparison among different ASEAN water quality indices for the assessment of the spatial variation of surface water quality in the Selangor river basin, Malaysia,” *Environ. Monit. Assess.*, vol. 192, no. 10, Oct. 2020, doi: 10.1007/S10661-020-08543-4.

[10] Z. Bin Luhaim *et al.*, "Drought Variability and Characteristics in the Muda River Basin of Malaysia from 1985 to 2019," *Atmosphere 2021, Vol. 12, Page 1210*, vol. 12, no. 9, p. 1210, Sep. 2021, doi: 10.3390/ATMOS12091210.

[11] "(PDF) Review of water quality standards and practices in Malaysia." Accessed: Aug. 11, 2026. [Online]. Available: https://www.researchgate.net/publication/292538407_Review_of_water_quality_standards_and_practices_in_Malaysia

[12] "View of Multiplication Factor of Actual Compressive Strength Relative to the Predicted Compressive Strength Obtained from Hammer Test Results." Accessed: Aug. 11, 2026. [Online]. Available: https://journalcendekia.com/SICEJ/article/view/8/6

[13] "View of Assessment of Awareness and Knowledge of Earthquake Disaster Mitigation among Residential Building Occupants in Padang City." Accessed: Aug. 11, 2026. [Online]. Available: https://journalcendekia.com/asdj/article/view/11/11

[14] H. M. Ateshan, R. Misnan, S. C. Sinang, and I. B. Koki, "Evaluation of water pollution and source identification in Merbok River Kedah, Northwest Malaysia," */ Malaysian Journal of Fundamental and Applied Sciences*, vol. 16, no. 4, pp. 458–463, 2020.

[15] "View of Characteristics of Intraslab Earthquake Waves." Accessed: Aug. 11, 2026. [Online]. Available: https://journalcendekia.com/SICEJ/article/view/1/2

[16] "View of Mapping of Individual Preparedness for Earthquakes in Padang City." Accessed: Aug. 11, 2026. [Online]. Available: https://journalcendekia.com/asdj/article/view/12/10