UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF MALAYSIAN RIVER STABILITY INDEX BY INCORPORATING MORPHOLOGICAL ASSESSMENT IN NORMAL FLOW CONDITIONS

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy.

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June 2021

Chair: Assoc. Prof. Badronnisa Binti Yusuf, PhD
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Various river-related issues continue to escalate throughout the year. The situation is exacerbated further when river stability assessment is extremely limited. Numerous rivers are unable to maintain an equilibrium flow regime, and unintentionally, Malaysia's rivers that have not been encroached upon have suffered due to the country's development. During development, too much suspended and bed sediment enters the river channel, and the channel undergoes excessive geomorphic responses, jeopardising the river's stability. Malaysia's Department of Irrigation and Drainage (DID) currently uses hydrodynamic modelling analysis to manage various river issues, including river pollution, erosion, and sedimentation. In the evaluation, the current methods were lacking in determining the river stability index. It is therefore essential to provide immediate attention to the development of the Malaysian River Stability Index (MRSI), which incorporates river morphological assessment in normal flow conditions as the primary goal of this research. Through tools and readily available results, MRSI enhances the evaluation of river stability. It is crucial to classify the selected rivers' physical and hydraulic properties, assess the river's flow regime, equilibrium hydraulics geometry, and geomorphic responses that changed the river's morphology, and develop MRSI's river stability incorporate a morphological assessment. The researcher carried out the research in five stages. In stage I, the site was chosen using the REFCON approach. The selected rivers were Lepoh, Congkak, Sekayu and Rasau River. In stage II, the extensive river measurement and laboratory work were completed. The raw data was then analysed in stage III to obtain hydraulic information. The physical and hydraulic elements of river morphology were identified in stage IV, where four forms of morphology have been studied: cascade, pool, step-pool, and plain bed. The flow regime and equilibrium hydraulics geometry analysis were then performed by charting the log-log graph as a power function of flow discharge and velocity, width, and depth. The geomorphic response of each river cross-section has been identified through a calculation based on the geomorphic response formula. Three steps are involved in stage V: (i) determining the index value for each sub-index (indicator) and selective criteria (optional criteria) of MRSI using the Analytical Hierarchical Process (AHP); (ii) developing the MRSI scoring system using the Likert Scale; and (iii) developing MRSI tools named S-MRSI using the Visual Basic application. AHP was the most suitable method to disentangle the inclination evaluations among the choices of index stability indicators using pairwise comparison. It was determined through AHP consistency that the highest index value indicates the most crucial indicator of river stability. The MRSI index, based on the Likert scale, indicates the degree of river stability, which consists of excellent (MRSI score 47–55), good (37–47), satisfactory (27–37), poor (17–27) and very poor (2–17). Several calibrations were performed by comparing the MRSI to the existing stability assessment. A Cronbach's Alpha value of 0.81 indicates that the stability assessment's consistency was robust. The MRSI and the existing stability index were equivalents.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN INDEKS KESTABILAN SUNGAI MALAYSIA DENGAN MENGGABUNGKAN PENILAIAN MORFOLOGI DALAM ALIRAN NORMAL

Oleh

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Pelbagai isu berkaitan sungai terus meningkat sepanjang tahun. Lebih memburukkan lagi keadaan apabila penilaian kestabilan sungai yang menggunakan pendekatan morfologi amatlah terhad. Banyak sungai tidak dapat mengekalkan rejim aliran keseimbangan, dan tanpa disedari, sungai-sungai di Malaysia yang belum pernah dicerobohi oleh perbuatan manusia telah tercemar akibat pembangunan negara. Semasa pembangunan, sejumlah besar sedimen terampai dan termendap memasuki saluran sungai, dan saluran itu mengalami tindak balas geomorfik yang berlebihan, lalu telah menjejaskan kestabilan sungai. Pada masa kini, Jabatan Pengairan dan Saliran (JPS) Malaysia menggunakan analisis model hidrodinamik untuk menguruskan pelbagai isu berkaitan dengan sungai, termasuk pencemaran sungai, hakisan, dan pemendapan. Dalam penilaian tersebut, analisis model hidrodinamik tidak mencukupi untuk menentukan indeks kestabilan sungai. Oleh itu, adalah penting untuk memberi perhatian segera kepada pembangunan Indeks Kestabilan Sungai Malaysia (MRSI), yang menggabungkan penilaian morfologi sungai dalam aliran normal, sebagai matlamat utama penyelidikan ini. Melalui penggunaan alat dan keputusan penilaian yang mudah, MRSI dapat meningkatkan penilaian kestabilan sungai. Untuk mencapai matlamat utama, adalah penting untuk mengukur dan mengklasifikasikan sifat fizikal dan hidraulik sungai-sungai yang telah dipilih. Kemudian, menganalisis rejim aliran sungai, keseimbangan geometri hidraulik, dan respons geomorfik yang mengubah bentuk sungai. Akhirnya, menggabungkan penilaian morfologi ke dalam pembangunan penilaian kestabilan sungai MRSI. Kajian ini dijalankan dalam lima peringkat. Pada peringkat I, tapak kajian ini dipilih menggunakan kaedah REFCON bagi memenuhi kriteria sebagai sungai rujukan. Sungai-sungai yang dipilih adalah Sungai Lepoh, Congkak, Sekayu dan Rasau. Pada Peringkat ke-II, kerja-kerja lapangan dan kerja-kerja makmal dijalankan dengan meluas untuk sungai-sungai tersebut. Data tersebut kemudian dianalisis di Peringkat ke-III untuk mendapatkan maklumat-maklumat hidraulik. Ciri-ciri fizikal dan hidraulik morfologi sungai telah dikenalpasti di Peringkat IV. Empat bentuk morfologi telah

dikaji: berlata, berkolam, kolam bertingkat dan berdasar seragam. Rejim aliran dan analisis keseimbangan hidraulik geometri kemudian dilakukan dengan memplot graf log-log sebagai fungsi kuasa pelepasan aliran dengan halaju, kelebaran, dan kedalaman. Tindakbalas geomorfik setiap keratan rentas sungai telah dikenalpasti melalui pengiraan berdasarkan formula tindakbalas geomorfik. Tiga Langkah-langkah yang terlibat dalam Peringkat V: (i) penentuan nilai indeks bagi setiap sub-indeks (petunjuk) dan kriteria terpilih (kriteria pilihan) MRSI dengan menggunakan Proses Analisis Hierarki (AHP); (ii) pembangunan skala MRSI dengan merujuk kepada Skala Likert, dan (iii) pembangunan system MRSI yang dinamakan oleh S-MRSI menggunakan Aplikasi Visual Basic. AHP adalah kaedah yang paling sesuai untuk menilai tahap kepentingan bagi setiap petunjuk kestabilan sungai melalui perbandingan satu per satu di antara setiap petunjuk tersebut. Ia ditentukan melalui indeks konsisten AHP, bahawa nilai indeks yang tertinggi menunjukkan bahawa penunjuk tersebut adalah yang terpenting dalam menentukan kestabilan sungai. Indeks MRSI, yang berdasarkan skala Likert, menunjukkan tahap kestabilan sungai, Cemerlang (MRSI Score 47-55), Baik (37-47), Memuaskan (27-37), Tidak Memuaskan (17-27) dan Sangat Tidak Memuaskan (2-17). Beberapa keselarasan telah dijalankan dengan membandingkan MRSI dan penilaian kestabilan sedia ada. Berdasarkan nilai konsistensi Alpha Cronbach iaitu 0.81, ini menunjukkan bahawa penilaian kestabilan itu teguh. MRSI dan indeks kestabilan yang sedia mempunyai kebersamaan.

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Nor Azidawati Haron, June 2021

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
ASTM	American Society for Testing and Materials
AHP	Analytical Hierarchical Procedure
ANOVA	Analysis of Varian
API	Application Programming Interface
HRA	Assessment of Hydrological Regime Alteration
BEHI	Bank Erosion Hazard Index
CCSI	Channel Condition and Stability Index
CSI	Channel Stability Index
CI	Consistency Index
CR	Consistency Ratio
DID	Department of Irrigation and Drainage of Malaysia
ER	Entrenchment
E	Excellent
EUWFD	European Union Water Water Framework Directive
GIS	Geographic Information System
G	Good
ISC	Index of Stream Condition
MRSI	Malaysian River Stability Index
MMULT	Matrix Multiplication Function
M	Morphological Assessment
MQI	Morphological Quality Index
OSEPI	Oklahoma Ozark Streambank Erosion Potential Index
FM	Pfankuch Method

PH	Physical Habitat Assessment
P	Poor
RI	Random Index
REFCON	Reference Condition
RH	Riparian Habitat Assessment
RHA	River Hydro-morphology Assessment Technique
S	Satisfactory
S-MRSI	Smart MRSI
TBM	Temporary Bench Mark
US	United States
VP	Very Poor
VBA	Visual Basic Application
WE	Water Elevation
WL	Water Level
WQI	Water Quality Index
w/d	Width to Depth

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Various issues related to the river have increased over time. These rivers have undergone significant morphological changes that have interfered with the river's ability to flow downstream—the changes to the form of river channels in terms of cross-section and channel plans. Because of the high suspended solid content, the clear water has turned yellowish and brownish. River flow becomes gradual due to the lower river slope. The river's energy deteriorates downstream, and the river's depth becomes shallow when more sediment materials accumulate at the bottom of the river. The significant change in the morphology has disrupted the stability of the river. These issues occur in the downstream area and threaten the rivers located upstream.

Among the activities that contribute to the encroachment on rivers are deforestation, land clearing, agricultural, river restoration, and rehabilitation activities such as channelisation, levee construction, concrete stabilisation, rip-rap, interconnected blocks, and other complex engineering control measures. As a result, the river’s stability has deteriorated. The ability of the river to flow in large quantities is crucial as they need to continuously supply enough water to sustain the river’s function for today and the future. In addition, the ecological value of the river has decreased, and the physical and biological biology have been threatened. These effects have a massive impact on aquatic life.

To prevent the river's stability from worsening, the evaluation of river stability needs to be extensive and regular. Existing river stability evaluations have been established in many developed countries, such as the United States, Australia, Germany, and other countries, since the 1980s. The countries in regional Asia also need to produce a river stability assessment to monitor the rivers in their countries at excellent stability (Ng et al., 2020). Similarly, research to evaluate river stability by incorporating morphological assessment is insufficient in Malaysia. It is critical to evaluate and manage activities in the river environment regularly to ensure that rivers do not get worse and the condition of river stability is maintained. River stability evaluations can assist with identifying potential improvement areas within the river cross-section and assist in achieving river management objectives more efficiently.

The most recent study on river stability assessment was conducted by Rinaldi et al. in 2016, where the assessment was named the Morphological Quality Index (MQI). The MQI approach is designed for the Italian river, where it is regionally designed for local conditions and meets the European Union Water Framework

Directive (EUWFD) requirements. The evaluation of river stability is based on professional judgment. Data collection requires GIS modelling, remote sensing, and topographic mapping. The MQI covered the full range of physical conditions, including physiographic units, hydrology and climatic conditions, and morphological rivers on a European scale. However, the MQI approach is unsuitable for Malaysia's rivers for various reasons, including unequal weather conditions, different types of rainforests and river basin catchments, and the approach's inadequacy for humid river regions.

To date, the Department of Irrigation and Drainage of Malaysia (DID) practices to control river pollution, erosion, and river mitigation using a hydrodynamic modelling analysis method (Aziz, 2021). Unfortunately, there are several limits to the practice of hydrodynamic modelling analysis in river stability assessment. Hydrodynamic modelling analysis acquires data from Geographic Information System (GIS) modelling, Hydrology, and Stream-flow. Data and information supplied by data acquisition are limited to specific locations where the measuring station is placed. Because of this, location recognition becomes complicated owing to a lack of data from places that may experience river instability.

Therefore, new developments through this research have been developed, the Malaysian River Stability Index (MRSI). The MRSI was developed based on the adaptability of rivers in humid regions with dense rainforest canopy cover, specifically designed for the Malaysian context, and was integrated with a morphological assessment to provide the best results in evaluating the river stability. This research was also prompted by the inapplicability of existing approaches, such as the MQI, which is very significant.

The invention of MRSI is based on significant data collection on a reach scale where evaluation is focused on the affected area, and evaluation is decided through quantitative analysis using the Microsoft Office Excel Visual (VBA) application. With this method, river stability can be evaluated more objectively and precisely, as opinions or interpretations do not influence it. Furthermore, although the location of the river needs to be analyzed is limited through satellite data, the MRSI can still be evaluated for the river stability analysis.

The MRSI will help evaluate the river stability, monitor the transformation of river morphology conditions regularly, and control and manage the river. Therefore, the MRSI can be applied in any sector or agency that handles river management and development. This study is an important starting point for river stability research in Malaysia; therefore, it should be emphasised for better progress on river stability.

1.2 Statement of Problems

The problem statement is divided into three major issues that served as the inspiration for this study. The main issues highlighted were a limited river stability index, eliminating not encroached rivers, and an excess of geomorphic responses. Consequently, the MRSI was created to overcome the problems by developing a river stability index. As a result, MRSI can:- (i) regularly monitor the rivers' conditions; (2) halt the deterioration of river stability near the development area by comparing the stability condition before and after the development, and; (iii) return the highly sedimented rivers to a stable state.

1.2.1 Limited River Stability Index Through the Use of A River Morphological Approach

The transformation of river morphology has largely been overlooked, especially in Malaysia, which includes alteration to river flow regimes, geomorphic responses, stream power conditions, slope, type of bed materials, morphology, and sediment load (Kirkby, 1977; Leopold & Wolman, 1957; Schumm, 1963). A river assessment protocol that utilises the river stability index has not yet been developed in Malaysia or any other country in Southeast Asia. There is an urgent need to bridge this gap (Ng et al., 2020). It is necessary to evaluate river stability regularly to prevent the river from worsening and maintain the ecological balance system. Although there are several existing methods, such as MQI, these methods are not appropriate for rivers in Malaysia. Ng et al., 2020 emphasised that assessment of the condition of the rivers in Malaysia, until recently, depended on physio-chemical monitoring and qualitative descriptions such as the Water Quality Index (WQI). While these approaches have produced some valuable results, they have generally failed to provide a consistent and comprehensive assessment of river conditions in river morphology regionally or nationally (Ng et al., 2020). With growing consensus on considering rivers as ecological systems, river stability indexes based on river morphological assessment are an alternative approach.

1.2.2 The Elimination of Malaysia's Not Encroached Rivers

As reported by the Department of Irrigation and Drainage, the government of Malaysia, only a few rivers in Malaysia are relatively not encroached (Sulaiman, 2009). Not encroached upon the river condition refers to the state of the river that is not disrupted by various activities, such as logging, land clearing, agricultural activities and so on, resulting in significant changes to the river morphology. Several streams, riparian, and catchment modifications affect most of the rivers. Malaysia is a fast-growing country with many areas built up for constructing skyscrapers, new cities, and commercial and business properties, resulting in far-reaching rivers and land changes (Sulaiman, 2009). Diverted and altered rivers due to human modifications such as deforestation, land conversion, etc., lead to significant changes in river morphology, which may cause flooding, excessive riverbank erosion, and extreme sediment degradation and aggradation, thus worsening the river ecology. Changing the affected rivers back to their original formation for river stability is impossible, but improving the impacted rivers is achievable.

1.2.3 Excessive Geomorphic Responses Have Jeopardised River Stability

The shape of a river changes through time due to geomorphic responses such as aggradation, degradation, and transportation of sediments in dynamic equilibrium. However, excessive geomorphic responses can cause the river morphology to be transformed and disturb the tranquillity of the flow regime. For example, the rapid velocity of water until the river bank collapses has led to the widening of the river, and the collapsed materials have formed a bar and pool. This occurrence has increased the river's carrying capacity, resulting in increased erosion and deposition. The situation also leads to additional long and meander belts of the river, thus changing the channel plan (Zhou & Endreny, 2020). If the geomorphic response occurs continuously, the river stability is threatened, and the environment is affected a long distance downstream through river networks (Haron et al., 2019; Kondolf & Piegay, 2003).

1.3 Research Objectives

Generally, this research aims to develop the river stability index by incorporating river morphological assessment into the Malaysian context. For this purpose, the objectives of this research are mainly focused on the following:

1) To classifies the physical and hydraulic features of river morphology,
2) To assess the variations of the coefficient and exponent through the flow regime and equilibrium geometry equation,
3) To evaluate the geomorphic response by incorporating the carrying capacity of the river that leads to the transformation of the river morphology,
4) To develop the Malaysian River Stability Index (MRSI) by incorporating morphological assessment in normal flow conditions.

1.4 Scope of Research

This study was carried out extensively at river reaches near mountains in Selangor and Terengganu. The selected rivers were based on the Reference Condition (REFCON) method, which provided appropriate river properties to serve as a reference condition. A total of four river reaches with a total of 34 cross sections were measured using the survey unit, hydraulics, and sedimentation equipment. The cross-section is chosen results in river morphology such as cascades, step-pools, pools, and plain beds with river slopes ranging from very steep (> 10%) to low (0.5%). However, pool rifles and dune rifles are not counted in this study because not all rivers indicate the presence of this morphology. The six types of raw data were measured, including velocity, bed materials, suspended load, bed load, the slope of water and river geometry. The measurements were taken during a normal flow condition. These data were analysed to determine hydraulic properties, geomorphic response, stream power, slope, and bed material type. Then, Visual Basic for Applications by Microsoft is used to develop the MRSI. The application of MRSI is valid for the range of typical flow. It is not applicable to flood flow or high flow.

1.5 Significant of Research

In Malaysia, theoretical knowledge regarding river stability factors and morphology transformations can be expanded more deeply. Understanding the diversity of morphological types is vital to balancing the stability of the river. Meanwhile, in practical terms, river stability assessments through MRSI are performed quantitatively and incorporated with Visual Basic for Applications to facilitate input and outcome data applications. Evaluation and result production of river stability has become easy and accurate. Indirectly, junior researchers and practitioners can use MRSI applications well.

1.6 Thesis Structure

This thesis is organised neatly to help the reader understand the content of this research. It contains five chapters, starting with the introduction in Chapter 1. The introduction will briefly explain the basics of establishing a river stability index, problem statements related to the issues of river morphology, research objectives, the scope of work and the significance of the research. Chapter 2 will explain the review of other methods of applying the stability index and the detailed facts of a mountainous river's morphology, including its characteristics and contextual details. Extensive literature about the parameters of river stability, flow regime and equilibrium geometry, morphological channel system, stream classification system, geomorphic response, carrying capacity, and stream power are also included in this chapter.

Chapter 3 will explain the research methodology. The background of the sampling location, data collection methods, and data analysis methods are all clearly defined. Chapter 4 is the most crucial part of this research because it shows the analysis to obtain the information from the data collection. The step-by-step calculation is explained clearly, including river morphology's physical and hydraulic features, the relationship between the flow regime and the hydraulic geometry, the carrying capacity, the geomorphic response determination, and the MRSI establishment. Some samples of calculation are shown to assist with the reader's understanding.

Finally, chapter 5 contains the study's conclusions, a reflective evaluation, and some recommendations for futureresearch.

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