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Review

Morphological Assessment of River Stability: Review of the Most Influential Parameters

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Abstract: River health assessments in the form of morphological approaches are crucial to determining the stability of a river system. Human interference in the natural river landscapes has altered the regime of river flows in the past. The catastrophes arising from the regime alteration are varied: excessive erosion and sedimentation, low carrying capacity, depletion of water yield, and many more. Past researchers have formulated numerous assessments to examine the stability of a river system. Still, arguments are prevalent due to the opinionated nature of the evaluation and a lack of parameters about river equilibrium. This paper reviews the past approaches to assessing channel stability by revisiting the most influential parameters adopted in the assessment process. An Analytical Hierarchy Process (AHP) was employed to find the prioritization of the selected parameters. This study found that a field survey is the most preferred method of river assessment instead of the other techniques such as remote sensing, modeling, and rapid field assessment. The most influential parameters (top 5) that determine the stability of a river system are (1) channel forms, (2) channel dimensions, (3) channel substrates, (4) channel pattern, and (5) bank profile. Those parameterizations are crucial to determining the stability of a river system.

Keywords: morphological assessment; channel stability; riverine landscape; river stability index; analytical hierarchy index

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Citation: Haron, N.A.; Yusuf, B.; Sulaiman, M.S.; Razak, M.S.A.; Nurhidayu, S. Morphological Assessment of River Stability: Review of the Most Influential Parameters. *Sustainability* **2022**, *14*, 10025. https://doi.org/10.3390/su141610025

Academic Editors: Jinsong Huang, Faming Huang, Shuihua Jiang and Zezhou Wang

Received: 14 July 2022
Accepted: 11 August 2022
Published: 12 August 2022

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1. Introduction

It is crucial to understand morphological assessment as an alternative way to maintain the river landscape and promote sustainable restoration of morphological appearance and aquatic and riparian habitats [1]. This branch of science involves studying how rivers shape the Earth's surface and its dynamics [2,3]. In recent decades, the hydrology and geomorphology fields of study integrated by imposing a morphological approach to account for the physical characteristics and stream processes simultaneously [4]. The EU Water Framework Directive [5] introduced the need for a morphological approach to assessing rivers within Europe by incorporating hydrological regime, river morphology, and river continuity. In Malaysia, the Department of Irrigation and Drainage [6] has implemented a National Water Balance Management System for Peninsular Malaysia to strengthen integrated water resources management in the Muda River Basin to replicate the system in other basins in the future. It is a computerized system based on several investigative studies into water demand and water. However, an assessment of river stability has not been discussed thoroughly, yet water availability by a stable channel is crucial and in dire need. Thus, abundant reports and literature showed the importance of preserving the river landscape through river assessment of channel stability. An in-depth review of available river assessments is given by [4]. They recommended that river condition assessment integrates with a few disciplinary approaches such as hydrology, geomorphology, water quality, biology,

and ecology. As a result of this, river health assessment can be broken down into four main groups: physical habitat assessment [7–14], riparian habitat assessment [1–22], hydrological regime alteration assessment [23–29], and morphological assessment [9,20,30–35]. These assessments differ due to the river section of interest and multiple integrations between fields of study.

Nevertheless, the parameters in each assessment are almost the same: a combination of hydraulics, hydrology, and geomorphology of the river landscape. In a nutshell, these assessments can represent hydro-morphological assessment methods. However, [1] criticizes hydro-morphological assessment methods, which emphasize qualitative approaches and are open to criticism because they are highly subjective and may appear to be opinionated. Thus, the role of quantitative and statistical analysis seems more realistic in validating and providing a check and balance for hydro-morphological assessments. The significance of these assessments may have an impact on future restoration work. The available project risk screening matrix for river management and restoration [36–38] employs parameters that have the potential to reduce or increase project impact potential. Those parameters are somehow in-line with the existing hydro-morphological assessment. Therefore, the parameters that controlled the geomorphic changes must be given full attention.

The main aim of this paper is to find the most influential parameters that control channel stability. The specific purposes of this paper are: (1) to review the existing parameters of hydro-morphological assessment and their associated categorical data, and (2) to assess the most influential parameters based on weightage segmentation. A review of the influential parameters was commenced by inferring from the previous report of [4]. A ready-made checklist by [4] will be used as a ground base to find the most influential parameters. The descriptions for each parameter are discussed based on the European Method for Water Framework Directive [39]. The morphological assessment group has given special attention to four river health assessment categories. Each parameter's prioritization and associated weightage were assessed using the analytical hierarchal process (AHP) methodology. The highest weightage indicates the most influential parameters in their sub-indexes. The most influential parameters provide a basis for controlling the factors in river landscape changes.

2. Materials and Methods

2.1. Inventory of Influential Parameters

Channel forms, geomorphic adjustments, and human alterations are the main criteria in morphological assessment [4]. Morphological assessment emphasizes the degree of deviation from unaltered rivers, which can be referred to as a reference condition. The reference condition is the condition of the river in an unaltered or least-degraded and most ecological dynamic state. An in-depth discussion on reference conditions was given by [20]. It can be concluded that inferring the reference condition from the past landscape is impractical. The rivers might continuously change on a temporal scale due to the persistent interrelationship between human activities and natural phenomena. Many authors have removed the past landscape as a reference condition [20]. As previously described by [40], the reference condition is best described by looking at the least degraded and most ecologically dynamic state. They claimed that a river system must be more autonomous and resilient to external perturbations. [41] proposed a reference condition designated as an expected state, the best shape the river can achieve to balance human alteration given the state of the catchment condition—data collection for previous morphological indexes or assessments based on the reference sites. Therefore, the obtained data at those most minor degraded sites best describe parameters that influence landscape changes.

A total number of 22 morphological methods that fall under the morphological assessment group was selected to find the weightage and ranking for each criterion, as shown by [4]. The inventory of the parameters was divided into three categories: data collection methods, recorded features, and physical river process features.

2.1.1. Data Collection Method

The data collection method (Table 1) is a theme that relates to gathering the data (source of information), the mechanism of storing the data (type of assessment), lengthwise variability, transverse variability, and time variability. Remote sensing includes a preliminary desk study providing topographic, geomorphology, groundwater maps, surveyed reach, land cover, geology, river network, the extent of riparian distribution, historical changes on planform/pattern, and information on artificial pressures [42–46]. The field survey sub-criteria measure several physical variables at the reach (transects) scale [47]. This task is time-consuming but a highly sought-after method to obtain ground databases. Ref. [44] argued that a field survey must cover 10% of the investigated river to verify the results of the desk studies protocol. Rapid field assessment requires well-trained operators and surveyors who know the morphology of a river system [48,49]. Modeling encompasses a gauged station's water level, discharge, and other hydraulic computations [50]. The percentage of occupied field survey is the highest and stood at 91%, while the modeling approach as a source of data information is the least and stood at 5% among 22 morphological methods.

Table 1. Inventory for Data Collection Method [4].

Inventory	Criteria	Sub-Criteria	Frequency%
Data Collection Method	Source of information	Remote sensing	73
		Field survey	91
		Rapid field assessment	9
		Modeling	5
	Type of Assessment	Inventorying	50
		Assessment by index	59
		General Assessment	50
	Longitudinal Spatial Scale	Fixed Length	9
		Length vs. width	14
		Variable-length	64
	Lateral Spatial Scale	Channel	100
		Riparian Zone	96
		Floodplain	86
	Temporal Scale	Present (last year)	100
		Recent (1–10 year)	7
		Historical (10–50 year)	7

This assessment consisted of three sub-criteria: inventorying, assessment by index, and general assessment. Inventorying is a feature based on a river system's frequency, extent, absence/presence, and morphological aspects [43,45,51–53]. Assessment by index mainly uses a functional-unit score system, where scores are assigned following a hierarchical/stepwise approach [52]. As such, [46] proposed that morphological parameters (for channels and banks) be assessed on a 5-point scale from 1 (natural) to 5 (anthropogenic). The general assessment is a method that aims to give a comprehensive evaluation of morphological conditions [7,50]. Each parameter is examined individually by the frequency, percentage, occurrences, etc. The rate of occupied space for each sub-criteria is almost the same, where assessment by an index is the highest compared to the other two. Spatial scale refers to the extent of a study area's land or geographical distance. Longitudinal spatial scale infers the streamwise extent of a river section. The proposed survey was conducted on segments 500 m long [45]. Instead, [43] suggested that for the 10 m width of a channel, the proposed longitudinal survey should cover 100 m long, 30 m width for 500 m long, and a width >30 m, the longitudinal survey should account for 1 km. However, both of them differed in the lateral survey. [45] proposed that the left and right banks must be surveyed together, while [43] suggested otherwise. Temporal scale refers to the time frame

of data collection for assessment. Most researchers utilize the present state of data for river assessment.

2.1.2. Recorded Features

Recorded features are parameters that were assessed in the field. Those parameters included the channel features, riparian zone features, floodplain features, and large-scale characteristics. These features were stratified according to the active channel, bank and riparian unit, floodplain, and mega form unit. Channel pattern, form, and substrate dominate the channel features for assessment purposes (82%, 86%, and 82%, respectively). Channel patterns entail the longitudinal shape of a river system, such as a straight, meandering, or braided channel. This parameter assesses the variability of channel width both currently and in the past [42,43], synonymously using the term "channel plan form" to illustrate the channel pattern parameter. Channel form is a recorded feature on the river bank or the main channel section [54]. The erosion and depositional characters, including bars and islands, were recorded in channel form. Two schools of thought exist on measuring the channel substrate; the dominant substrate in the river bed [51,52] and the degree of naturalness of bed substrate composition (compared to the reference) [50]. The bank and riparian unit feature close to the water's edge. The bank profile scored the highest preference frequency, 82%, while species composition achieved the least, at 18%. The bank profile and shape measure the bank extent and slope, variability of cross-section, and eroding/stable cliff features [55,56]. Floodplain features are the width of the whole floodplain and potentially erodible corridors [20]—all sub-criteria share almost the same frequency, as depicted in Table 2. The mega form unit and its associated flow regimes record large-scale characteristics. Ref. [20] emphasized the segmentation phase of geology, geomorphology, climate, and land use in large-scale settings. The channel-forming discharges, which influence morphological processes, were considered in the hydrological regime.

Table 2. Inventory for Recorded Features criteria [4].

Inventory	Criteria	Sub-Criteria	Frequency%
Recorded Features	Channel features	Channel pattern	82
		Channel form	86
		Channel dimension	73
		Flow type	27
		Substrate	82
		Physical parameters	32
		In-channel vegetation	27
		Woody debris	50
		Artificial features and structures	77
	Banks/riparian zone features	Bank profile/shape	82
		Bank material	36
		Riparian vegetation structure	64
		Riparian vegetation continuity	32
		Riparian vegetation width	27
		Species composition	18
		Artificial features and structures	77
		Land use	46
	Floodplain features	Fluvial forms	46
		Floodplain dimensions	41
		Floodplain features	32
		Land use	46
	Large scale characteristics	Large scale pressure	68
		Hydrological regime/discharge	82
		Valley form	64

2.1.3. River Processes

River processes as tabulated in Table 3 are the themes that relate to the physical and geomorphic form of a river landscape resulting from fluvial processes. These criteria somehow overlapped with the other parameters in the recorded feature's inventory. Bank erosion and channel adjustment share the highest degree of frequency in the river process criteria. Bank erosions were assessed in a few manners: observation of cross-section naturalness and presence of protection structure [50,54,57,58]; determination of unit stream power to assess the capacity of the river to erode river bank [47], and bank profile and retreat [20,44,52,55]. They set the channel adjustment by looking at the historical changes to the channel form due to the introduction of hydraulic structures [20,50,58,59].

Table 3. Inventory for River Processes criteria [4].

Inventory	Criteria	Sub-Criteria	Frequency%
River Processes	River Processes	Longitudinal continuity	55
		Lateral continuity	68
		Large-scale sediment connectivity	36
		Bank erosion/stability	82
		Channel adjustments	82
		Vertical connection (groundwater)	16

2.2. The Analytical Hierarchy Process (AHP)

This study used Analytical Hierarchy Process (AHP) to determine the most influential parameter for morphological assessment. The AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales [60]. As illustrated by [61], the AHP process involves four main steps: (1) Knowing the problem statement and the type of decision to be made; (2) creating the decision hierarchy by segregating different levels of judgment; (3) constructing a set of pairwise comparison matrices; (4) assigning the weightage priorities for each element. The AHP method performed a pairwise comparison before eigenvalue computation. Table 4 gives the fundamental scales of pairwise comparison to prioritize different elements in the hierarchy process. The eigenvalues were then designated as the weightage or rank for each element and were computed using the following principles:

i. The values (prioritize numbers as in Table 4) in each column of the pairwise comparison matrix were summed;
ii. Column total divided each element of the matrix. This operation will normalize all column values in the pairwise matrix;
iii. The elements in each row (previously converted into a decimal form) were then averaged to obtain a priority vector. The row average is the weightage of each component, which can then be translated into a ranking classification (the highest the weightage, the greater the rank).

Table 4. Prioritize number [61].

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor
6	Strong plus	

Table 4. *Cont.*

Intensity of Importance	Definition	Explanation
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

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3. Results

3.1. Weightage and Ranking at Criteria Level

The AHP assessed three primary inventories separately and used normalized eigenvalue computation before ranking classification. Those inventories are data collection methods, recorded features, and river processes. Before executing the eigenvalue computation, it is crucial to determine the priority number between each pairwise. The priority number can be extracted from the frequency percentage as stipulated in Tables 1–3. For example, the source of information criteria consists of four sub-criteria, namely remote sensing (73%), field survey (91%), rapid field assessment (9%), and modeling (5%). As shown in Table 5, the baseline for normalization took the highest total frequency for any criteria; in this case, the channel feature criteria stood at 536%. After normalization, the frequencies for the source of information and type of assessment were 33.20% and 29.6%, respectively. Thus, the percentage difference was 3.5%, which falls under the preference scale of 1, favoring the source of the information criteria. Executing the AHP steps as mentioned in the previous section reveals that the weights for the source of information, type of assessment, longitudinal spatial scale, lateral spatial scale, and temporal scale were 4.3%, 4.3%, 2.6%, 9.7%, and 4.7%, respectively. The final weightage of 4.3% was assigned to all sub-criteria within the source of information criteria and vice versa. This set of weights at the criteria level is called global weightage (GW), which accounts for 100% of the total eigenvalues. The ranking in Table 5 reveals that data collection methods focusing on lateral spatial scale governed the most effective techniques in assessing river stability patterns. The lateral spatial scale encompasses the permanently flowing channel and the zone of the full bank state [48]. Recorded features inventory reveals that channel features are the most influential criteria in assessing the morphological assessment of a river system. The sub-criteria in Table 2 for channel features indicated the parameters acquired to set spanning from microform to the mega form of a river system.

3.2. Weightage and Ranking at Sub-Criteria Level

An assessment must be conducted separately since two hierarchy levels are involved (criteria and sub-criteria). The difference in frequency percentage served as a benchmark for selecting a preference scale, as discussed in Section 3.1. The bi-polar questionnaire was prepared as a tool for pairwise comparison. Pairwise comparison is a technique of comparing elements in pairs or aspects of the same criterion. The number of questions for each measure can be determined using $\frac{n(n-1)}{2}$ where; n represents the number of sub-criteria for each main criterion.

For source of information sub-criteria, the number of bi-polar questions is $4(4-1)/2 = 6$. An excel spreadsheet determines the preference for each criterion. Figure 1 shows an example of a bipolar question for each measure.

Table 5. The percentage of frequency for each criterion.

		Data Collection Method					Recorded Features				River Process
Criteria		**Source of Information**	**Type of Method/ Assessment**	**Longitudinal Spatial Scale**	**Lateral Spatial Scale**	**Temporal Scale**	**Channel Features**	**Riparian Zone Features**	**Floodplain Features**	**Large Scale Characteristics**	**River Process**
Sub	1	73	50	9	100	100	82	82	46	68	55
	2	91	59	14	96	36	86	36	41	82	68
	3	9	50	6	86	46	73	64	32	64	36
	4	5		4			27	32	46		82
	5						82	27			82
	6						32	18			18
	7						27	77			
	8						50	46			
	9						77				
Total percentage		178	159	33	282	182	536	382	165	214	341
Normalization (%)		33.20	29.66	11.94	52.61	33.95	100	71.26	30.78	39.92	63.62
Eigenvalues (%)		4.3	4.3	2.6	9.7	4.7	35.4	16.1	4.6	5.1	13.2
Ranking for Main Criteria		3	3	5	1	2	1	2	4	3	1

		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-9)
1	2	Remote sensing	Field survey	B	2
1	3		Rapid field assessment	A	6
1	4		Modelling	A	7
1	5				
1	6				
1	7				
1	8				
2	3	Field survey	Rapid field assessment	A	7
2	4		Modelling	A	8
2	5				
2	6				
2	7				
2	8				
3	4	Rapid field assessment	Modelling	A	1
3	5				
3	6				
3	7				
3	8				

Figure 1. -Bi–polar questionnaires.

Columns A and B are elements of the same criterion. As discussed, preference must be made between A and B to choose the essential component between these two. Then, the preference scale was assigned from 1 to 9. A matrix of 4 × 4 was created to find the eigenvalues for the bi-polar questionnaire. Numbers 1 to 4 on both axes represent the elements in the sub-criteria. From Table 5, it is well understood that a field survey was the preferred choice instead of remote sensing, with a scale of 2. Thus, a preference scale of 2 and the typical value of that scale were assigned, as shown in Figure 2.

	1	2	3	4
1	**1**	1/2	6	7
2	2	**1**	7	8
3	1/6	1/7	**1**	1
4	1/7	1/8	1	**1**
col sum	3 1/3	1 3/4	15	17

Figure 2. Comparison matrix at the same criteria for the source of information criteria.

The following eigenvector values were obtained for the source of information sub-criteria (see Figure 3) using the procedure previously discussed in methods (Section 2). The normalized principal eigenvector for the field survey is the highest and stood at 52.98%. This weightage is herein inferred as "local weightage" (LW). It can be concluded that the field survey was the most effective data collection method compared to the other ways (i.e., remote sensing, modeling, etc.). Performing field surveys for river assessment was the most reliable source of data from the river system. The normalized principal eigenvector can be translated into a ranking system, as shown in Figure 4. As a rule of thumb, the highest weightage represents rank one among the studied sub-criteria and vice versa. This process was performed for the other sub-criteria for the entire inventories. The highest multiplication between GW and LW gave the overall rank that represented the most influential criteria across the inventories to obtain the overall rank. Table 6 summarises all sub-criterias' global weight, local weight, and overall rank. The channel form, dimension, substrate material, channel pattern, bank profile, bank erosion/stability, channel adjustment, channel constriction, artificial feature, and riparian zone sat in the top 10 for the most influential parameters among 47 parameters.

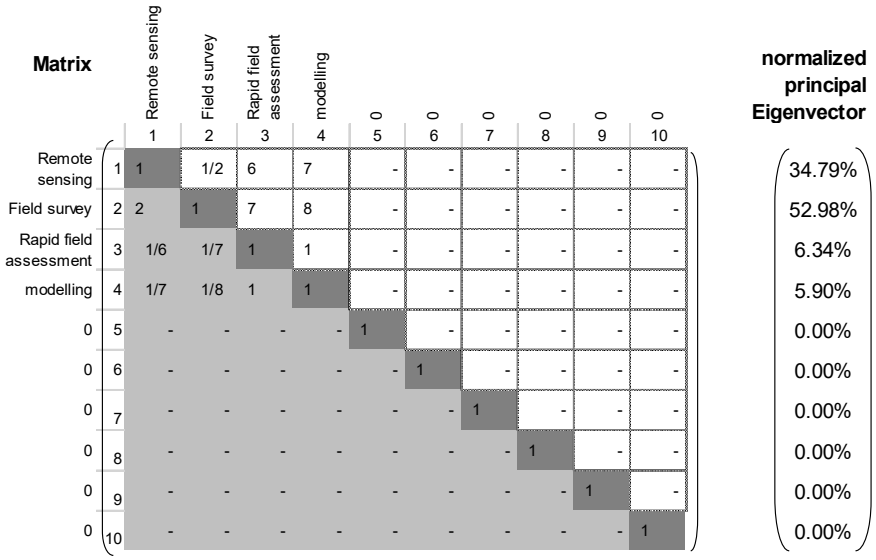


Figure 3. Normalized principal eigenvector for the source of information criteria.

	Criterion	Comment	Weights	Rk
1	Remote sensing		34.8%	2
2	Field survey		53.0%	1
3	Rapid field assess		6.3%	3
4	modelling		5.9%	4
5				
6				
7				
8				
9		for 9&10 unprotect the input sheets and expand the		
#		question section ("+" in row 66)		

Figure 4. Ranking for the source of information sub-criteria.

Table 6. Summary of global weight, local weight, and overall rank.

Inventory	Criteria	Sub-Criteria	GW%	Rank	LW%	Rank	Overall Ranking
Data Collection Method	Source of Information	Remote Sensing	4.3	3	35.0	2	21
		Field Survey			53.0	1	17
		Rapid Field Assessment			6.0	3	45
		Modeling			6.0	3	45
	Type of Assessment	Inventorying	4.3	3	33.33	1	23
		Assessment by Index			33.33	1	23
		General Assessment			33.33	1	23
	Longitudinal Spatial Scale	Fixed Length	2.6	5	14.3	2	43
		Length vs. Width			14.3	2	43
		Variable Length			71.4	1	19
	Lateral Spatial Scale	Channel Constriction	9.7	1	41	1	8
		Riparian Zone			33	2	10
		Floodplain			26	3	15
	Temporal Scale	Present (last year)	4.7	2	65	1	11
		Recent (1–10 year)			14.5	3	40
		Historical (10–50 year)			15	2	39
		Monthly			4.7	4	47

Table 6. *Cont.*

Inventory	Criteria	Sub-Criteria	GW%	Rank	LW%	Rank	Overall Ranking
Recorded Features	Channel Feature	Channel Pattern	35.4	1	16.9	4	4
		Channel Form			22.6	1	1
		Channel Dimension			19.3	2	2
		Flow Type			3.8	7	27
		Substrate			17.2	3	3
		Physical Parameter			4.5	6	20
		In Channel Vegetation			3.8	7	27
		Woody Debris			8.1	5	12
		Artificial Features			3.8	7	27
	Vegetation Regeneration	Bank Profile	16.1	2	28.5	1	5
		Bank Material			6.4	5	34
		Riparian Vegetation Structure			13.6	4	18
		Riparian Vegetation Continuity			5.3	6	36
		Riparian Vegetation Width			4.8	7	38
		Species Composition			3.5	8	41
		Artificial Feature and Structure			20.6	2	9
		Land Use			17.2	3	13
	Floodplain Feature	Fluvial Form	4.6	4	30	1	26
		Floodplain Dimension			25	2	32
		Floodplain Features			21	4	35
		Land Use			25	2	32
	Large Scale	Large Scale Pressure	5.1	3	25	2	30
		Hydrological Regime			50	1	14
		Valley Form			25	2	30
River Process	River Process	Longitudinal Continuity	3.2	1	11.3	4	22
		Lateral Continuity			17.9	3	16
		Large Scale Sediment Connectivity			6.2	5	37
		Bank Erosion/Stability			30.4	1	6
		Channel Adjustment			30.4	2	6
		Vertical Connection			3.9	6	42

3.3. Consistency Checking

The quality of the ultimate decision relates to the consistency of judgments demonstrated during the pairwise comparisons. A consistency ratio (CR) exceeding 0.10 is indicative of inconsistent rulings. A sample of inconsistency is given: If, A > B; B > C, then A > C. If A < C, then inconsistency is said to exist. Each value in the first column of the pairwise comparison matrix was multiplied by the normalized eigenvector of the first item. Other criteria incurred the same procedures. Sum the values across the rows to obtain a vector of "weighted sum" values.

$$0.348\begin{bmatrix}1\\2\\1/6\\1/7\end{bmatrix}+0.53\begin{bmatrix}1/2\\1\\1/7\\1/8\end{bmatrix}+0.063\begin{bmatrix}6\\7\\1\\1\end{bmatrix}+0.059\begin{bmatrix}7\\8\\1\\1\end{bmatrix}=\begin{bmatrix}0.348\\0.696\\0.058\\0.049\end{bmatrix}+\begin{bmatrix}0.265\\0.53\\0.076\\0.066\end{bmatrix}+\begin{bmatrix}0.378\\0.441\\0.063\\0.063\end{bmatrix}+\begin{bmatrix}0.413\\0.472\\0.059\\0.059\end{bmatrix}=\begin{bmatrix}1.404\\2.139\\0.256\\0.237\end{bmatrix} \quad (1)$$

The corresponding eigenvector value divided the elements of the vector of weighted sums such that

$$\begin{bmatrix} 1.404/0.348 \\ 2.139/0.53 \\ 0.256/0.063 \\ 0.237/0.059 \end{bmatrix} = \begin{bmatrix} 4.034 \\ 4.036 \\ 4.063 \\ 4.016 \end{bmatrix} \quad (2)$$

The lambda maximum averaged the ratios in Equation (2) as follows:

$$\lambda_{max} = \frac{4.034 + 4.036 + 4.063 + 4.016}{4} = 4.037 \quad (3)$$

The Consistency Index (CI) can be obtained as follows:

$$\text{CI} = \frac{\lambda_{max} - n}{n - 1} = \frac{4.037 - 4}{4 - 1} = 0.0123 \quad (4)$$

Consistency Ratio (CR) was calculated by dividing CI and Random Index (RI) given by [60]:

$$\text{CR} = \frac{\text{CI}}{\text{RI}} = \frac{0.0123}{0.89} = 0.014 < 0.10$$

Since CR for the source of information criteria is less than 0.10, the pairwise comparison is consistent and correct. Overall, the pairwise comparison for all criteria and sub-criteria was shown in Table 7.

Table 7. Consistency ratio for Sub-criteria.

Sub-Criteria	Number of Sub-Criteria	Lambda	Consistency Ratio
Source of Information	4	4.037	1.40×10^{-2}
Type of assessment	3	3.000	0.00
Longitudinal Spatial Scale	3	3.000	0.00
Lateral Spatial Scale	3	3.054	6.00×10^{-2}
Temporal Scale	4	4.104	3.80×10^{-2}
Channel Feature	9	9.715	6.18×10^{-2}
Vegetation Regeneration	8	8.738	7.53×10^{-2}
Floodplain Feature	4	4.060	2.22×10^{-2}
Large Scale Characteristics	3	3.000	0.00
River Process	6	6.074	1.18×10^{-2}

4. Discussion

The main essence of this paper is to review the plausible parameters that lead to the identification of river stability status and restoration works. The outcomes from the AHP analysis were presented in the form of weightage and ranking. Two conditions of weightage exist, global weightage (GW) and local weightage (LW). GW represents the eigenvalues for the main criteria, while LW represents the eigenvalues for sub-criteria. The highest weightage is denoted as rank 1 for both GW and LW. As [62] discussed, the GW and LW are multiplied to obtain the highest weightage. Thus, the first rank in the influential parameters finds the overall rank.

The data collection method entails gathering the data and info, ways of keeping the data, and the spatial and temporal scale of data collection. The data collection method theme assessed five (5) criteria and sixteen (16) sub-criteria. The main criteria were the source of information, type of assessment, longitudinal spatial scale, lateral spatial scale, and temporal scale. Under the source of information, four (4) sub-criteria were reviewed:

remote sensing, field survey, rapid field assessment, and modeling approaches. A field survey is the most preferred approach to identifying hydro-morphological data as opposed to remote sensing, rapid assessment, and modeling. Inventorying, assessment by index, and general evaluation shared equal preference due to their flexibility and ease of data-keeping. For longitudinal scale, the variable length of data sampling is the most preferred to extract the morphological condition data instead of fixed length. It is a plausible approach due to the variability of river reach, and the selection of fixed length may skip the apparent dynamics of river morphology at different scales.

The channel constriction for the lateral scale seems critical for stability assessment. The constriction may induce regime alteration downstream or upstream from the constriction point. Thus, the stead on river constriction instead of floodplain or riparian zone is more prevalent at the lateral scale. The temporal scale states the time window of data analysis or collection to assess morphological changes. Four major temporal scales were considered: present (last year), recent (1–10 year), historical (10–50 years), and monthly. The most present data are preferred instead of the recent or historical record to assess the morphological condition or selected site. It is true if the baseline data are needed to formulate the long-term stability of river conditions. The criteria for data collection formed the best approach to the data sampling regime and the data collection scale to represent the study area's overall condition.

Recorded features form the primary essence in the morphological assessment of river stability. The influential parameters can be perused from these categories, which can be divided into four (4) main categories: channel feature, vegetation regeneration, floodplain feature, and large-scale flow and river landscape. Based on global weightage, channel features, vegetation regeneration, large-scale features, and floodplain features formed the 1st, 2nd, 3rd, and 4th rank. The sub-categories in channel features, channel forms, channel dimensions, substrate, channel pattern, and woody debris are ranked in the top 5 based on the LW values.

River processes represent the action of water on the river geometry and the impact thereof. The sub-categories in river processes are longitudinal continuity, lateral continuity, large-scale sediment connectivity, bank erosion/stability, channel adjustment, and vertical connection. Based on LW values, bank erosion and channel adjustment are the most preferred parameterization in the river processes category.

The higher rank in the sub-criteria does not necessarily represent the same rank should the overall be considered. As such, the first rank for the sub-criteria in vegetation regeneration can have a lower overall rank than the third in the channel features category.

5. Conclusions

A few conclusions can be drawn concerning the optimum assessment of river stability in the future. The findings are as follows:

iv. Regarding data collection methods, lateral spatial scales are the most common place for researchers to look for data instead of horizontal spatial scales in the past;
v. Field sampling dominates the information source compared to remote sensing, modeling, and rapid field assessment techniques;
vi. The most sought-after parameters in the morphological assessment are channel features (cross-sectional features), followed by river bank sections (including their properties), large-scale features, and floodplain features;
vii. The most influential parameters that control the river stability following the weightage and ranking are (1) channel form; (2) channel dimension; (3) substrate material; (4) channel pattern; (5) bank profile; (6) bank erosion/stability; (7) channel adjustment; (8) channel constriction; (9) artificial features and, (10) riparian zone.

Based on the top ten (10) most influential parameters for determining channel stability, there is no parameter on the flow and sediment dynamics that shape the river landscape. Therefore, morpho-dynamic parameters should play a key role in assessing channel stability. Future river assessment can incorporate the riverine threshold, regime equation, and stable

channel carrying sediment. These parameters emphasize the dynamics of flow and deposit in the riverine system. Regime equations highlight the best hydraulic geometry for a stable channel because a stable channel design stresses the best river width and slope to maintain the incoming and outgoing sediment. Including morpho-dynamic parameters is expected to shift the future river assessment paradigm.

Author Contributions: Conceptualization, N.A.H. and M.S.S.; methodology, N.A.H. and M.S.S.; validation, B.Y. and S.N.; formal analysis, N.A.H.; investigation, N.A.H.; resources, N.A.H.; data curation, M.S.S.; writing—original draft preparation, N.A.H.; writing—review and editing, M.S.S. and B.Y.; supervision, M.S.S., B.Y. and M.S.A.R.; funding acquisition, B.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Putra Graduate Initiative Grant grant number GP-IPS/2018/9654200, and The APC was funded by Putra Graduate Initiative Grant.

Institutional Review Board Statement: Not Applicable.

Informed Consent Statement: Not Applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The author gratefully acknowledges the financial support from the Putra Graduate Initiative Grant (GP-IPS/2018/9654200) from the University of Putra Malaysia. The author highly appreciated the continuative support, guidance, and thoughtful comments from the Supervisor and Co-Supervisors from the University Putra Malaysia and the University Malaysia Terengganu on completing this research.

Conflicts of Interest: The authors declare no conflict of interest.

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