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Research Article

Verifying and Weighting Factors Using Fuzzy Delphi Method Approach in the Construction of Public Perception Index (PPI) on River Quality

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Abstract: Water pollution remains a critical concern for Malaysian rivers, particularly due to increasing urbanization, industrial activities, and climate change. These factors have significantly degraded river quality through erosion, sedimentation, and pollution, disrupting the traditional relationship between communities and rivers. The Terengganu River, for instance, has experienced a marked decline in water quality, largely attributed to irresponsible human practices such as improper waste disposal. Previous research underscores the need for enhancing public ecological awareness. This study aims to develop a Public Perception Index (PPI) to assess and enhance community awareness of river pollution, especially among populations residing near rivers. Using the Fuzzy Delphi Method (FDM), 25 expert participants evaluated and validated key assessment criteria. From an initial set of eleven factors, eight were retained based on consensus analysis. The FDM results identified government roles as the most influential factor, while urbanization ranked lowest in importance. These weighted factors were incorporated into a composite index, leading to the formulation of a general mathematical model for the PPI. The study presents a novel approach to quantify public perception and promote environmental awareness, contributing to sustainable river management efforts in Malaysia.

***Keywords*:** river quality, water pollution, public awareness, fuzzy delphi method, composite index, mathematical formulation

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1. Introduction

There is no life on earth without river systems since rivers are the primary source of water for all life on earth [1]. The river is one of the most important ecological commodities essential to the preservation and advancement of the

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country. Due to the importance of rivers in providing groundwater, trade routes, drainage, and electricity, this becomes vital. Consequently, rivers are essential not just for humans but also for animals and plants to survive [2, 3].

River quality refers to the state of a river's biological, chemical, and physical attributes, quality encompasses the overall health of a river system, measured by indicators like water chemistry, biological diversity, habitat conditions, and physical parameters. It reflects the river's ability to support aquatic life and meet human needs for drinking water, recreation, and industry [4]. River pollution is a highly pressing issue requiring various parties' holistic efforts to find solutions [5]. Generally, each river in this country is categorized into five classes:

• Class 1-water that is safe for direct consumption without treatment.

• Class 2-water requires regular treatment.

• Class 3-water appears clean, odorless, but its quality is compromised, and the public cannot swim but can picnic along its banks.

• Class 4-polluted*.

• Class 5-nearly dead*.

The quality of Malaysia's rivers is degrading based on water quality assessment in Malaysia [6, 7]. The Water Quality Index (WQI) indicates that 219 (46%) of the 477 managed rivers are clean, 207 (43%) are slightly polluted, and 51 (11%) are polluted in 2017, according to [6]. In contrast to 27 (75%) rivers with safe water services, 8 (22%) with a highly polluted index, and 1 (3%) with polluted water in 2012, the report found that 10 rivers in Terengganu are classified as class 2 and 14 have a slightly polluted index with class 3. This indicates a decline in the amount of pure water in the state. Communities who live near rivers, such as grocery traders, processed keropok factories, batik shops, seafood markets, cafes, and restaurants, should pay more attention to the degradation of water purity in the Sungai Hilir in Terengganu [8]. Officials from the Terengganu State Water Systems Ministry claimed that around RM 3.3 million had been allocated as maintenance expenses of the Sungai Hilir in Terengganu. Despite millions of ringgit being spent, a reasonable understanding and cognizance of the need for river maintenance remain weak and somewhat at a disappointing level. On the other hand, if the general public possessed a high level of cognizance in protecting rivers from pollution, the government could save state expenditures up to hundreds of thousands of ringgit each year.

The community still needs to learn more about the value of protecting rivers. Previous studies have shown that the general public needs help to comprehend environmental issues' natural causes [9]. Even though most people know the difficulties faced, they need help understanding the facts about eutrophication [10]. This situation indicates that despite reasonable cognizance given, the public still are unaware of the existing issues. The current climate system, in which rivers threaten human existence, is primarily a result of human actions [3, 11, 12]. Communities can prevent pollution problems in rivers and water sources. They can enhance their quality of life, as well as their well-being and protection, by implementing and practicing green initiatives. The majority of environmental problems can be attributed to irresponsible attitudes among people, according to [9]. Various stakeholders must take action to ensure that the public understands the importance of proper maintenance for the river. [10] emphasize that the general public indeed does not take the matter seriously and often acts carelessly by treating rivers as dumping grounds, even though the reality is that the majority of water pollution is caused by an individual's lack of knowledge about the impact of their actions on water pollution issues.

The only community's source of knowledge about river pollution was their own observation, besides knowing that the main cause of pollution was illegal garbage dumping [13]. Therefore, this study takes an initial step to educate the awareness of river pollution for residents who live near the river. A Public Perception Index (PPI) on river quality is necessary to educate the public about maintaining river cleanliness to uphold river water quality. It is important for the preservation of local rivers; where residents living nearby need to be educated about the fact that river water pollution can result from improper waste disposal, livestock waste and farming runoff, toxic waste dumping, and others. This is important to be carried out to verify and weigh the factors contributing to the river pollution for the construction of the public perception index. This formulation index can be the assessment of river quality levels in terms of understanding, mindset, and behavior starts with the Terengganu, among those living along the banks of the Terengganu River, regarding water pollution issues.

2. Literature review

The continuous assessment conducted by the [6] clearly shows that the quality of the country's rivers is at an uncertain level. In 2017, a decline in groundwater recharge, as measured by the Water Quality Index (WQI), was observed. It was discovered that, despite 46% of rivers being categorized as clean in 2017, this number was declining when compared to 2015, when 58% of rivers were in the same category. As a consequence, the number of rivers classified as polluted also increased from 7% in 2015 to 11% in 2017 [6]. This data shows that pollution can pose a dangerous threat to the quality of Malaysian rivers and have long-term impacts on the country's water supply.

2.1 *Factors of river pollution*

According to [14], in the 21st century, society faces many major challenges in terms of water quality. If the grand challenge is not addressed, several Sustainable Development Goals (SDGs) will be jeopardized. Water quality issues are brought to the forefront of international action by the 2030 Agenda and Sustainable Development Goals (SDGs). Goal 6 specifically targets ensuring the availability and sustainable management of water and sanitation for all to address water quality challenges [15]. Tun Ismail et al. [16] believed various river pollution problems have existed in recent times as a result of human activities. Human activities have profound and often detrimental impacts on river quality, influencing their physical, chemical, and biological characteristics. These impacts stem from various sources and activities, which disrupt the natural balance and health of river ecosystems.

One of the human activities that affect the river quality is agricultural practices. It contributes significantly to river pollution through runoff containing fertilizers, pesticides, and herbicides. Recent studies highlighted the significant impact of agricultural runoff on river water quality. Nutrients like nitrogen and phosphorus from fertilizers often lead to eutrophication, which results in algal blooms and decreased oxygen levels, harming aquatic life and reducing biodiversity [14, 17]. Other than that, industrial activities often lead to the release of pollutants such as heavy metals, toxic and chemicals which can accumulate in the food chain, posing risks to both wildlife and human health. The contaminants and untreated wastewater into rivers led to detrimental effects on aquatic organisms and human health. Industrial pollution introduces heavy metals and toxic chemicals into rivers [5, 18]. Another human activity that affected the river quality is mining operations. Research by [19] discussed the detrimental effects of mining on river ecosystems. Mining operations often lead to increased sedimentation and contamination of water with heavy metals, impacting both aquatic life and water quality.

Chen et al. [20] and Hatt et al. [21] reviewed the impact of urbanization on river ecosystems, focusing on changes in water quality and habitat conditions due to increased storm water runoff. The expansion of urban areas leads to increased impervious surfaces, such as roads and buildings, which enhance storm water runoff. This runoff can carry pollutants like oils, heavy metals, and litter into rivers. In addition, [22] examine how land use changes and deforestation contribute to river sedimentation and water quality degradation. Deforestation and changes in land use can lead to increased erosion and sedimentation in rivers. Kumar et al. [23] provide insights into the long-term effects of land use changes on river water quality. Their study, spanning 30 years, demonstrates how shifts in land use such as deforestation and urban sprawl can lead to altered sediment loads, nutrient dynamics, and water quality degradation over time. While [24] analyzed the effects of wastewater on river ecosystems, emphasizing the importance of effective wastewater management practices. The discharge of untreated or inadequately treated sewage and wastewater from households, industries, and sewage treatment plants can introduce pathogens, organic matter, and nutrients into rivers. This can lead to increased Biochemical Oxygen Demand (BOD), promoting the growth of harmful bacteria and algae, and further degrading water quality. Smith et al. [25] evaluate the improvements in river quality resulting from upgrades in wastewater treatment facilities. Enhanced treatment processes have led to reductions in nutrient and pathogen levels, contributing to better overall river health.

The government is also a part of the reason of degraded river quality. Meyer et al. [26] emphasized the crucial role of riparian vegetation in maintaining river quality. Healthy riparian zones act as buffers, reducing runoff, filtering pollutants, and providing habitat for wildlife. Unfortunately, due to the weak enforcement and action, the loss of such vegetation can significantly impact water quality and ecosystem health. The historical cycle witnessed a decrease in the quality of these natural resources and it became the most common problem in Malaysia [3].

There are also contextual and inefficient influential components within the community. Even though there have been numerous initiatives implemented, yet hydrological improvements are still evident as a result of the ongoing lack of public awareness about cleanliness. This closely relates to the overall attitudes of the general public, comprising producers of goods, livestock herders, and residents near rivers who fail to make the most of river cleanliness and instead of View Rivers as a solution to daily problems. This attitude can be seen as one of the factors causing polluted and hazardous rivers [27, 28]. According to a previous study done by [16], to have a peaceful river environment, society must understand and comprehend the negative effects of individual behaviour and be involved in the development of these behaviors. A wide range of issues are examined in the study of [29] including knowledge, values, attitudes, perceived behavioral control, self-efficacy, subjective norms, exposure to environmental messages through the media, recycling facilities, intention, and community behaviour.

2.2 *FDM*

One of the widely used in many researches for various purposes is The Fuzzy Delphi Method (FDM). It is advancement over the traditional Delphi Method, which has drawbacks such as low convergence in extracting outcomes, loss of vital information, and a lengthy investigation. The basis of FDM is structured surveys and input from selected experts for the study. The experts can be defined by the researcher according to the context and criteria needed for the research. FDM has been employed as a study methodology in earlier studies carried out in Malaysia and other nations. The main focus of these studies was to identify and priorities components based on their importance in developing models, modules, and assisting in decision-making [30]. One of the most familiar purposes is getting consensus among experts about an issue in a research. It is a flexible tool for decision making based on the experts' view [31]. Therefore, the FDM suits the purpose of this study which is to verify the factors and weightage for factors of river pollution in order to create a mathematical formulation of awareness index.

2.3 *The composite index*

The composite index is one of the mathematical formulations that able to measure the muti-dimensional concept of a context. The Organization for Economic Cooperation and Development (OECD) [32] emphasized that the utilization of composite index should be grounded on a theoretical framework that allows for the selection, combination, and weighting of individual indicators or variables to reflect the dimensions of measurable phenomena. It has been widely utilized in many sectors to analyze, forecast and provide a useful benchmark especially economy, business management and education too.

3. Materials and methods

The most important in the methodology that used in the research are Fuzzy Delphi Method (FDM) to verify and weight factors and Composite Index to construct the general formulation of Public Perception Index (PPI) on river quality.

3.1 *The utilization of FDM to verify and weight factors*

This study utilized Fuzzy Delphi Method (FDM) to verify and weight the factors of river pollution emerging from the first phase of this study. The first phase of this study started with identifying the significant factors that impact river quality through a preliminary literature review and semi-structured interviews with experts in river quality such as researchers, lecturers and officers in Department of Environmental (DOE). A questionnaire was prepared with the list of emerging factors with 7 points Likert scales. In order to gather agreement from people perspectives and to weigh all factors, this study will utilize the FDM technique in the second phase. The questionnaire prepared was distributed to 25 respondents representing those who live by the river bank of Terengganu and Kelantan. The diversity of expertise ensures a comprehensive perspective on the various impacts of human activities on river systems. They were asked to rate their consensus on each factor (individual fuzzy ratings) using the Likert scale. The Fuzzy aggregation techniques are applied to combine individual fuzzy ratings into a collective fuzzy score for each criterion. This step involves calculating the fuzzy mean and determining the consensus level. Next, the factors are ranked based on their aggregated fuzzy scores. These weightages are very important for the calculation of the composition index in mathematics. The calculation of the index that gives high marks indicates that the level of river pollution which is low, medium and high [30, 33–38] based on the public perspectives. The Likert scales chosen by the experts will be converted into Fuzzy Scales by referring to [39] as shown in Table 1.

Table 1. 7-Point likert scale conversion table to fuzzy scale

Likert scale	Level of agreement	Fuzzy scale
7	Extremely strongly agree	(0.9, 1.0, 1.0)
6	Strongly agree	(0.7, 0.9, 1.0)
5	Agree	(0.5, 0.7, 0.9)
4	Moderately agree	(0.3, 0.5, 0.7)
3	Disagree	(0.1, 0.3, 0.5)
2	Strongly disagree	(0.0, 0.1, 0.3)
1	Extremely strongly disagree	(0.0, 0.0, 0.1)

The data analysis using FDM is based on two pre-requirement. The first pre-requirement is the Triangular Fuzzy Number as Equation (1). It refers to the threshold value, d should be more or equal to 0.2 and the expert consensus that should be more or equal to 75%. The formulation of Triangular Fuzzy Number is shown in Equation (2):

$$d\left(\widetilde{m},\,\widetilde{n}\right)=\sqrt{\frac{1}{3}\left[\left(m_1-n_1\right)^2+\left(m_2-n_2\right)^2+\left(m_3-n_3\right)^2\right]}, \tag{1}$$

whereas:

m_1 = the minimum value, m_2 = the reasonable value and m_3 = the maximum value.

The consensus of the expert panel must be at least 75%. (expert consensus $\geq$ 75%).

The second requirement is the Fuzzy Evaluation Process. It refers to the Fuzzy score shown in Equation (3) that should be more or equals to 0.5. The Fuzzy Evaluation Process will represent the acceptance and rank for every factor or criteria in this study.

$$A_{\max}=\frac{1}{3}\times\left(m_1+m_2+m_3\right). \tag{2}$$

3.2 *The mathematical formulation of public perception index on river quality using composite index*

The basic formulation of composite index as shown in Equation (3) [30, 34, 40]:

Composite Index,

$$\bar{I}=\frac{\sum\left(I_i w_i\right)}{\sum w_n}, \tag{3}$$

whereas:

$i = 1, 2, 3, \ldots, 8$ and $n = 1, 2, 3, \ldots, 8$.

$\underline{I}$ = Composite index.

I = index number for each component.

w = weightage for each component identified by FDM analysis.

The formulation will be also used for identification of key indicators that interpret the public perception index value.

4. Results and discussion

There two parts in this section which are included verifying and weighting process of factors contributed to river pollution by Fuzzy Delphi Method (FDM) and construction of public perception index on river quality formulation.

4.1 *The verifying and weighting process of factors that contributes to river pollution by FDM*

The factors that contribute to water pollution have been emerged from the thematic analysis in the first phase of this study. Next, the factors will be verified and weighted using FDM analysis. The results from the formulated Microsoft Excel developed by [39] in Table 2.

Table 2. Summarization of FDM analysis result

River awareness factors	Condition of triangular fuzzy numbers		Condition of defuzzification process	Expert consensus
	Threshold value ($d < 0.2$)	Percentage of experts group consensus (> 75%)	Fuzzy score ($A_{max} \geq 0.5$)	
Awareness	0.176	88.0%	0.861	Accepted
Attitude	0.233	84.0%	0.836	Accepted
Urbanization	0.234	76.0%	0.763	Accepted
Ship traffic	0.378	52.00%	0.692	Rejected
Sand mining activity	0.202	68.00%	0.728	Rejected
Role of government	0.097	92.00%	0.913	Accepted
Poor drainage systems	0.174	96.00%	0.807	Accepted
Livestock farming	0.154	100.00%	0.828	Accepted
Illegal dumping	0.272	84.00%	0.809	Accepted
Discharge of untreated waste	0.268	88.00%	0.819	Accepted
Agriculture runoff	0.221	68.00%	0.748	Rejected

Out of eleven factors emerged from the first phase of the study, eight factors were accepted and three factors were rejected by the FDM analysis. The rejection of factors was because they did not meet the requirement of Triangular Fuzzy Numbers for threshold value and experts group consensus which appears to be one of the initial conditions of FDM. However, four factors, namely attitude, urbanization, illegal dumping, and untreated water discharge, were tolerated despite the fact that they did not meet the first threshold value criteria. The researchers decided to accept the factors due to two reasons. The first reason was that respondents' agreement on the FDM and Fuzzy score for those factors met the requirements. The second reason was that these factors emerged frequently during interviews with river quality experts. The interview was the first stage of the research. Next, the ranks of factors were determined based on the Fuzzy Score and the weightage were assigned based on the rank. The highest rank will get the highest weightage which is eight, followed by others as in Table 3.

Table 3. The rankings and weightages of factors based on the fuzzy score

Factors	Fuzzy score	Rank	Weightage
Role of Government (RG)	0.913	1	8
Awareness (AW)	0.861	2	7
Attitude (AT)	0.836	3	6
Livestock Farming (LF)	0.828	4	5
Discharge of Untreated Waste (UW)	0.819	5	4
Illegal Dumping (IL)	0.809	6	3
Poor Drainage Systems (PD)	0.807	7	2
Urbanization (URB)	0.763	8	1

The most critical factor identified based on the FDM was the role of government. The government plays a vital role in regulation and enforcement that can ensure sustainability of river management, policy development, funding and investment, coordination to facilitate collaboration among various stakeholders across different sectors and raising public awareness. This is aligned with the significant role of government discussed in [41]. Awareness is found to be the second critical factor for effective river quality and management. Increasing the awareness about the benefit of healthy river ecosystems can lead to more responsible behavior by individuals. By having awareness, there will be greater support for government policies and regulations. It also helps in preventing and mitigating the impacts of river pollution. It was supported by [42]. While, attitudes affect individual and organizational behaviors related to river management. Positive attitudes towards environmental protection are associated with behaviors that reduce pollution and promote conservation. This finding was aligned with [3, 11, 12]. All other factors are related to human activities from farming or agriculture to the urbanization. These findings matched with the previous studies as discussed.

4.2 *The construction of public perception index on river quality formula*

The mathematical formulation of public perception index on river quality is constructed from the base formulation of composite index in the Equation (3) and the weightages of factors from FDM results as shown in Equations (4)-(6).

$$\bar{I} = \frac{[Iw_{RG} + Iw_{AW} + Iw_{AT} + Iw_{LF} + Iw_{UW} + Iw_{ID} + Iw_{PD} + Iw_{URB}]}{(w_{RG} + w_{AW} + w_{AT} + w_{LF} + w_{UW} + w_{ID} + w_{PD} + w_{URB})} \tag{4}$$

$$\bar{I} = \frac{[w_1 \sum_{i=1}^{n} a_i + w_2 \sum_{i=1}^{n} b_i + w_3 \sum_{i=1}^{n} c_i + w_4 \sum_{i=1}^{n} d_i + w_5 \sum_{i=1}^{n} e_i + w_6 \sum_{i=1}^{n} f_i + w_7 \sum_{i=1}^{n} g_i + w_8 \sum_{i=1}^{n} h_i]}{(8+7+6+5+4+3+2+1)} \tag{5}$$

The index, $\bar{I}$ in Equation (4) is the summation product of the sub index and assigned weightages from FDM for every component. Next, assuming that the role of government comprises five items in the questionnaire, the summation scores of the items will be multiplied by the allotted weightage in FDM, which is 8, to generate the sub index for that component. Therefore, if we replacing eight emerging factors in this study with $a, b, c, ..., h$ and has n number of items in the developed questionnaire, thus the Equation (4) can be restated as Equation (5).

Thus, the general formulation of Public Perception Index on river quality can be represented as:

$$\bar{I} = \frac{[8 \sum_{i=1}^{n} a_i + 7 \sum_{i=1}^{n} b_i + 6 \sum_{i=1}^{n} c_i + 5 \sum_{i=1}^{n} d_i + 4 \sum_{i=1}^{n} e_i + 3 \sum_{i=1}^{n} f_i + 2 \sum_{i=1}^{n} g_i + 1 \sum_{i=1}^{n} h_i]}{36} \tag{6}$$

whereby:

a_i = the sum of Likert scale rated according to respondents regarding the role of government which consists of n items.

b_i = the sum of Likert scale rated according to respondents regarding the awareness which consists of n items.

c_i = the sum of Likert scale rated according to respondents regarding the attitudes which consists of n items.

d_i = the sum of Likert scale rated according to respondents regarding the livestock farming which consists of n items.

e_i = the sum of Likert scale rated according to respondents regarding the discharge of untreated waste which consists of n items.

f_i = the sum of Likert scale rated according to respondents regarding the illegal dumping government which consists of n items.

g_i = the sum of Likert scale rated according to respondents regarding the poor drainage system which consists of n items.

h_i = the sum of Likert scale rated according to respondents regarding the urbanization which consists of n items.

With this established formulation, we may use human perspectives rather than relying on regular inspections by the Department of Environment Malaysia as the primary safety measure to assess river quality. Additionally, this index may alert the public-especially those who reside along riverbanks about changes to the river caused by pollution. The formulation of public perception index on river quality is a novelty effort using the parameters of human activities compared to common indexes that based on the water samples tested at the laboratory through the inspection. Thus, the people can take part to prevent the river quality from getting worse.

5. Conclusions

The government bodies can create and implement policies that guide river management with well-designed policies that integrate scientific findings, stakeholder input, and management goals to address river quality issues effectively. The implementation of targeted education programs that address specific knowledge gaps and promote positive behaviors related to river conservation. Educational and outreach programs can be tailored to shift attitudes in a positive direction, encouraging practices such as reduced use of harmful chemicals, better waste management, and support for local conservation initiatives. Moreover, the findings from this study or expert panels can inform policy development by highlighting priority issues and areas needing intervention. The policy makers can develop the local community-based monitoring and reporting using user-friendly tools such as PH sensors, sampling bottles and color charts for turbidity. By leveraging the findings from the FDM, stakeholders can make informed decisions that address the most pressing issues impacting river quality, ultimately leading to more effective and sustainable river management practices. The methodology's limitations include potential biases and the subjective nature of expert opinions and the limitations in the fuzzy logic approach. Therefore, it is suggested that future research to expand the expert panel, refining criteria, and compare the results using other weightage method as well.

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Conflict of interest

There is no conflict of interest for this study.

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