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ENHANCING SUSTAINABILITY INDEX PARAMETER USING ANFIS COMPUTATIONAL INTELLIGENCE MODEL

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ABSTRACT: The scarcity of water resource is an essential global issue in the 21st century. Therefore, one of the Sustainable Development Goals (SDG) was to ensure the availability and sustainable management of water and sanitation. To do this, it is necessary to assess whether or not the SDG has been followed using the sustainability index. However, there are a lot of sustainability indexes and many of them have the same problem, in which all sustainability index parameters have the same weightage. This problem shows us that every parameter in the sustainability index is equal, while in real life there is no equal parameter. In this paper a weightage for each parameter is proposed to enhance the sustainability index. The method to assess the sustainability index parameters was using a questionnaire by key experts in the water industry. Using ANFIS computational intelligence, the result of the assessment was then fit to the frequent parameters that exist in other sustainability indexes. This proposed method can produce a ranking and weight for each sustainability index parameter and criteria. Using this method, the weightage for each sustainability index parameter can be generated, such as environmental 0.301, engineering 0.214, economic 0.280, and social 0.205.

ABSTRAK: Kekurangan sumber air merupakan isu global yang penting dalam abad ke-21. Oleh itu, salah satu Matlamat Pembangunan Mampan (SDG) adalah bagi memastikan ketersediaan dan pengurusan air dan sanitasi yang berterusan. Bagi melaksanakan ini, adalah perlu untuk menilai sama ada SDG telah diikuti atau tidak menggunakan indeks kemampanan. Walau bagaimanapun, terdapat banyak indeks kemampanan dan kebanyakannya mempunyai masalah yang sama, di mana semua parameter indeks kemampanan mempunyai pemberat yang sama. Masalah ini menunjukkan kepada kita bahawa setiap parameter indeks kemampanan adalah sama, manakala dalam kehidupan sebenar tiada parameter yang sama. Kajian ini merupakan cadangan wajaran pemberat bagi setiap parameter bagi meningkatkan indeks kemampanan. Kaedah bagi menilai parameter indeks kemampanan adalah menggunakan soal selidik oleh pakar utama dalam industri air. Menggunakan kecerdasan pengiraan ANFIS, hasil penilaian kemudiannya diselaraskan dengan parameter kerap yang wujud dalam indeks kemampanan lain. Kaedah yang dicadangkan ini boleh menghasilkan pemeringkatan dan pemberat bagi setiap parameter dan kriteria indeks kemampanan. Menggunakan kaedah ini, wajaran pemberat bagi setiap parameter indeks kemampanan dapat dijana, seperti persekitaran 0.301, kejuruteraan 0.214, ekonomi 0.280, dan sosial 0.205.

KEYWORDS: *Sustainability Index, Computational Intelligence, ANFIS, Weightage, Water Industry.*

1. INTRODUCTION

In 2022, Indonesia's economy improved, with economic progress in both urban and rural areas. Increased employment in the agricultural, manufacturing, transportation, and logistics services sectors contributed to poverty reduction [1]. Likewise, in the Tangerang Region, Indonesia, which has seen an increase in per capita income, the total population is also growing very fast. Consequently, water needs also increase [2]. Apart from having a positive impact, it also poses new challenges in terms of water availability in the future [3, 4]. Water resources are key ecosystem components that sustain life and all social and economic processes. The scarcity of water resources is an essential global issue in the 21st century [3–6] Adequate water availability is challenged by population growth, rapid urbanization, and climate change in meeting urban water needs [7, 8]. Therefore, the second target of SDGs seeks to ensure the availability and sustainable management of water and sanitation until 2030, emphasizing the quality and sustainability of water resources in integrating and balancing the three dimensions of sustainable development such as economic, social, and environmental [9].

Although there is an increasing trend toward using sustainability index to support plans for long-term, medium-term, and short-term sustainable development, the sustainability index is not infallible on its own. This has been the cause for creation of many new sustainability indices such as the SWaM index, the Canadian Water Sustainability index, and many more [10, 11]. Even though there have been some instances of success with the use of these new and current sustainability indices, they are not entirely relevant in all applications. This was brought on by some of the sustainability indices that were created for usage in particular nations or regions [12]. One could argue that there isn't a universal gauge of water sustainability. However, in the current sustainability index, the parameters don't have weightage. The example of this can be seen in the WSSI index. This implies a problem in the sustainability index foundation, in which evaluation components are considered to have equal weight, hence making sustainability measurement inaccurate.

The aim of this paper is to develop the best sustainability index. To achieve that aim, the objective of this paper will be to combine input from various experts and computational intelligence methods [13]. There are many computational intelligence methods, such as neural network, fuzzy, and other [14–16]. However, in this paper ANFIS is prefered because it combines the fuzzy method with the neural network method [17]. This combined approach makes ANFIS preferable compared to the others. ANFIS is preferred due to its transparency in associations (reasoning to generate the membership functions and rules from a set of training data) to reach the optimal predicted value [18]. This paper proposed an ANFIS method to create differing weightage for every sustainability index parameter and create more accurate sustainability measurements.

2. METHOD AND DESIGN

In this section, the method used in this research is explained. The technique used includes questionnaires with experts and ANFIS computational intelligence.

2.1. Adaptive Neuro Fuzzy Inference System (ANFIS)

Zadeh developed the foundation of fuzzy in 1975 based on Linguistic Variables and their application to Approximate Reasoning [19]. The fuzzy rule was subsequently created to model the qualitative elements of human knowledge (reasoning based on experience) and address the issue using those as its foundations [20] Fuzzy logic is typically employed for control, including robot movement, and many others [21–24], however in reality, a fuzzy system can be applied to anything from detection to forecasting [25-26]. In 1985, Takagi and Sugeno

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created Fuzzy Sugeno [27]. The fuzzy implications and reasoning system control were shown using this mathematical model [28–30]. The Fuzzy Sugeno equation can be seen in equations 1 through 6.

$$O_i^1 = \mu A_i(x) \text{ and } O_i^1 = \mu B_i(x), i = 1,2 \tag{1}$$

Where:

i = each node of ANFIS architecture.

A, B= is the linguistic label.

x = is the input to node i. (such as small, large, etc.).

Every membership function type is usable at this stage. However, to offer a maximum equal to 1 and a minimum equal to 0, generalized bell types were employed. hence:

$$\mu Ai(x) = \frac{1}{1 + \left(\frac{x-c_i}{a_i}\right)^{2*b_i}} \tag{2}$$

where:

a,b,c= is the parameter set.

By multiplying the two input signals, the second step contributes to the firing strength of fuzzy inference. This is represented by each node.

$$O_i^2 = \mu A_i(x).\mu B_i(x), i = 1,2 \tag{3}$$

The following phase involves applying normalization for each fuzzy inference firing.

$$O_i^3 = \overline{W_i} = \frac{W_i}{W1+W2}, i = 1,2 \tag{4}$$

where:

W= is the firing strength of the node.

$\overline{W_i}$= is the normalized firing strength of the node.

The following phase involves a calculation based on the parameters of the rule consequent in the following phase:

$$O_i^4 = \overline{W_i}.F_i = \overline{W_i}.(P_i x + Q_i x + R_i x), i = 1,2 \tag{5}$$

where:

P,Q,R = is the parameter set

The final phase computes the overall output by adding up all of the input signals:

$$O_i^5 = Overall\ Output = \sum_{k=0}^{n} \overline{W_i}.F_i = \frac{\sum_{k=1}^{n} W_i.F_i}{\sum_{k=1}^{n} W_i} \tag{6}$$

Jang Jyh Shing Roger created Adaptive Neuro Fuzzy Inference System (ANFIS) in 1993 based on fuzzy Takagi Sugeno's IF-THEN rules [31]. The fuzzy inference system can adapt organically using the ANFIS approach based on its training data. The Takagi-Sugeno fuzzy inference system serves as the foundation for the artificial neural network technique that makes up ANFIS [32]. This method can combine the benefits of fuzzy logic and neural networks into a single framework: a collection of fuzzy IF-THEN rules that can be learned to estimate nonlinear functions govern how this inference system operates. Consequently, ANFIS is regarded as a Universal Estimator (universal assessor). Equations 2 through 7 make up the core

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algorithm used by ANFIS, which uses a Fuzzy Sugeno algorithm. Jang then used gradient descent and chain rule to optimize its parameter. However, to do this, it must be aware of the error rate for data training for each node output, since ANFIS learns through chain rule and gradient descent. The ANFIS algorithm can be seen from equation 7 through Equation 12:

If the data training sets have P numbers of inputs and the i-th position node outputs define o_i, then the error function may be calculated as follows:

$$E_p = \sum_{m=1}^{\#L} (T_{mp} - O_{mp}^{L})^2 \tag{7}$$

where:

E_p = is the error measure which is the sum of squared errors.

T_{mp} = is the m component from the P output target vector.

O_{mp}^{L} = is the m component from the actual output vector that has been delivered by the P input vector.

Hence, the error rate can be calculated as:

$$\frac{\partial E_p}{\partial O_{ip}^{k}} = \sum_{m=1}^{\#k+1} \frac{\partial E_p}{\partial O_{mp}^{k+1}} \frac{\partial O_{mp}^{k+1}}{\partial O_{ip}^{k}} \tag{8}$$

Where 1 ≤ k ≤ L-1 is the error rate of an internal node. It is expressed as the linear combination error rate of nodes in the next step. Therefore, for all 1 ≤ k ≤ L and 1 ≤ i ≤ #(k), the $\frac{\partial Ep}{\partial O_{ip}^{k}}$ can be found using mathematical equations (7) and (8). Thus, a parameter of the adaptive network α can be written as:

$$\frac{\partial E}{\partial \alpha} = \sum_{O*\epsilon S} \frac{\partial Ep}{\partial O*} \frac{\partial O*}{\partial \alpha} \tag{9}$$

where:

S= shows the set of nodes whose output depends on α. Derivative for overall error measurement E concerning α is:

$$\frac{\partial E}{\partial \alpha} = \sum_{O*\epsilon S} \frac{\partial Ep}{\partial O*} \frac{\partial O*}{\partial \alpha} \tag{10}$$

Therefore, the updated mathematical equations for generic parameter α as follows:

$$\Delta\alpha = -\eta \frac{\partial E}{\partial \alpha} \tag{11}$$

where:

η = is a learning rate.

The learning rate can be written as:

$$\eta = \frac{k}{\sqrt{\sum_{\alpha} (\frac{\partial E}{\partial \alpha})^2}} \tag{12}$$

where:

k = is the step size or length of each gradient transition in the parametric space.

2.2. Sustainability Index Assessment Using Questionnaire with Key Experts in the Water Industry

The assessment of water supply sustainability might well be classified into three methodological methods that were established sequentially throughout time but are still in use today and are mutually supplemented, enhanced, and integrated [33]. Sustainability Development is defined by three interconnected components (environment, social, and economy), often known as aspects. Since the focus of this study is water management sustainability, the assessment of its sustainability must include extra components such as engineering components related to its intrinsic features [33–35]. The engineering component is adapted to the operating conditions of the water treatment which may affect the management of water utilities and affect environmental, social, and economic aspects. Furthermore, for this paper, the Sustainability Assessment framework is created by grouping key indications into four major components (Engineering, Environmental, Economic, and Social).

The questionnaire's primary components are in connection with the water sustainability index's theoretical model. A literature review was used to construct the framework, which consists of an initial set of components, indicators, and threshold values based on sustainability theories, water management principles, and existing water sustainability indexes from the CWSI, WSSI, WJWSI, WSI, and WPI. Criteria in designing this conceptual framework are critical for reducing researcher bias.

The questionnaire's contents include the respondents' importance ratings in the component/indicator/threshold values on a 4-point Likert scale. Where a value of 4 is 'very important', a value of 3 is 'important', a value of 2 is 'less important' and a value of 1 is 'very less important'. Questionnaires were distributed to several key experts who have backgrounds related to drinking water companies in Indonesia, especially piped drinking water in the Tangerang area. The parameter that is assessed using questionnaires by key experts can be seen in Table 1 below.

Table 1: Sustainability Index Parameter used for Questionnaire.

Component	Indicator	Sustainability Index (Existing)					Literature
		CWSI	WSSI	WJWSI	WSI	WPI	
Engineering	Water Losses	√	-	√	-	-	[36]–[42]
	Operational and Maintenance	√	√	√	√	-	[40], [43]–[46]
Environment	Quality	√	√	√	√	√	[42]–[44], [46]–[48]
	Quantity	√	√	√	√	√	[40], [43]–[46], [48]–[50]
	Continuity	√	√	√	√	√	[40], [43]–[46], [48]–[50]
Economic	Capital Investment	√	√	-	√	-	[46], [51], [52]
	Cost recovery & Operation and maintenance cost	-	√	-	-	-	[46], [51], [52]
	Ability to Pay	√	-	-	-	√	[43], [44], [48]
Social	Access for Water Supply	√	√	√	√	√	[40], [42], [43], [46], [51]
	Access for Sanitation	√	-	√	-	√	[42], [43], [46], [53], [54]

3. RESULT AND DISCUSSION

The findings of this research are presented in this section. The first step would be to start with the survey results from important water industry operation specialists. The ANFIS computational intelligence used the survey results to provide values that fit the frequently occurring sustainable index parameter. The weightage and ranking for each parameter of the sustainable index are generated in this way.

3.1 Questionnaire Result from The Experts

The assessment of the water sustainability index was carried out with a key expert in the water industry. Figure 1 shows the ranking of the sustainability index parameter as a result of using 10 parameters from different sustainability indices in Table 1.

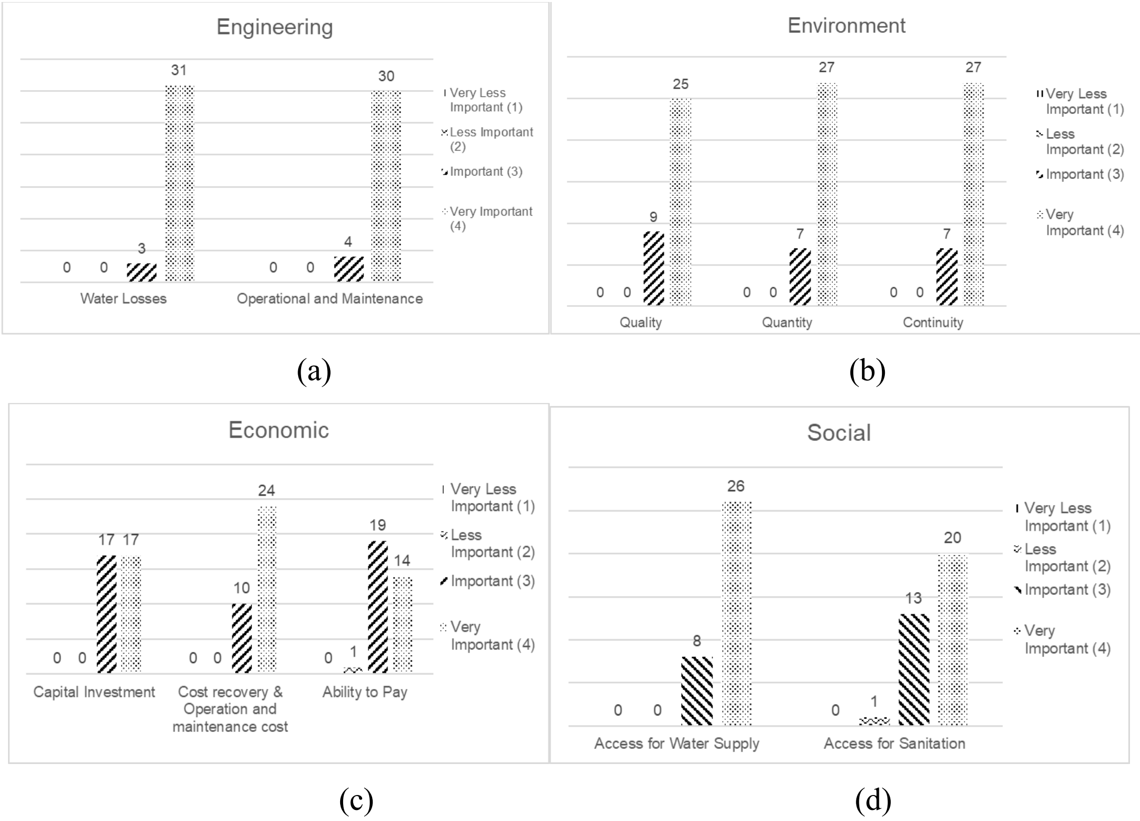

Fig. 1. Water Sustainability Index Assessment by Key Experts in the Water Industry. (a) Engineering Parameter, (b) Environment Parameter, (c) Economic Parameter, (d) Social Parameter.

3.2 ANFIS Fitting Model for Questionnaire and frequent Parameter Sustainability Index

Assisted by the ANFIS algorithm, a fitting model for the questionnaire result and frequent parameters that exist in most Sustainability Indices can be developed easily. The questioner data in Table 1 is data training for ANFIS. Thus, using Equation 2 and Equation 6, an ANFIS Fitting Model can be produced as shown in figure 2, Table 2, Table 3, Table 4, and Equation 13. In Figure 2, the generalized bell membership function is used for ANFIS fuzzification model fitting. Its membership function was formed by three parameters such as a, b and c. Using those parameters, the visualization can be built such that parameter a defines the width of the membership function input, while parameter b defines the shape of the curve on either side of the midland, and parameter c defines the center point of the membership function.

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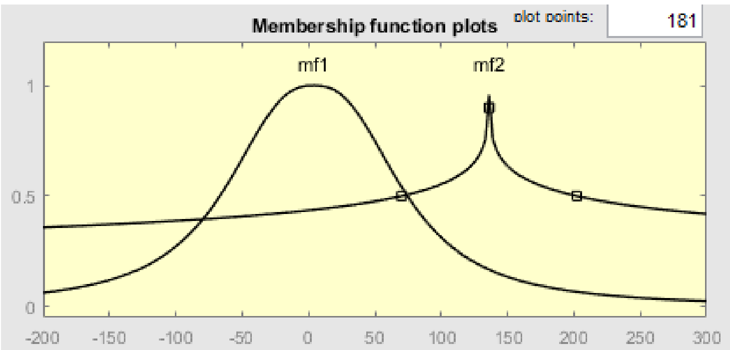

Fig. 2. ANFIS Fuzzification fitting model for the questionnaire and frequent parameter Sustainability Index.

Table 2: ANFIS Fuzzification fitting model for the questionnaire and frequent parameter Sustainability Index.

Fuzzification Input	a	b	c
mf1	70.7	1.283	3.825
mf2	65.97	0.1787	136.1

Table 3: ANFIS inference for Sustainable Index Parameter Weighting

Rule Index	Rule Firing	Rule Output
1	If (input is mf1)	Then Output is F1
2	If (input is mf2)	Then Output is F2

Table 4: ANFIS fitting model Fuzzy Constant Output

Output Constant Index (Fi)	Value
1	-2.484
2	5.234

Thus, the fitting ANFIS model for the questionnaire and frequent parameters that exist in Sustainability Index can be seen in equation 13 below:

$$= \frac{\sum_{k=0}^{n} \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^{2*b_i}\right]} + \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^{2*b_i}\right]} F_{i=1}^{n}}{\sum_{k=0}^{n} \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^{2*b_i}\right]} + \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^{2*b_i}\right]}} \tag{13}$$

Where:

x = Input variables in this research were questionnaire.

a, b, c= Defines the width of the membership function input as a, while b defines the shape of the curve on either side of the midland, and c defines the center point of the membership function.

$F_{i=1}^{n}$ = Defines the output variables' constant Level generated automatically by ANFIS based on the number of fuzzy rules/inferences. In this case, it refers to the parameter that often appears in the sustainability index.

n= Number of fuzzy rules/inferences.

Using the Fuzzy Sugeno fitting model on equation 13, the weight for each Sustainability Index parameter was determined. However, the value was normalized so that it ranged between a minimum of 0 and maximum of 1. Hence, calculating the total value of all fitting values from ANFIS is necessary to get this weight. The fitting value of each parameter will then be divided by the ANFIS's overall fitting value. This will establish the relative importance of each parameter which, when added together, will result in a value of 1. Therefore, the normalized weightage for each sustainability parameter can be seen in Table 5.

Table 5: Sustainability Index weight and ranking parameter result using ANFIS fitting.

Total Criteria Weight	Indicator	Index	Questionnaire Score	ANFIS Fitting	Ranking	Normalize Weight
Engineering (0.214)	Water Losses	E1	133	3,77	1	0,108
	Operational and Maintenance	E2	132	3,72	2	0,106
Environment (0.301)	Quality	E4	127	3,5	7	0,100
	Quantity	E6	129	3,58	3	0,102
	Continuity	S4	126	3,46	8	0,099
Economic (0.280)	Capital Investment	E7	120	3,23	9	0,092
	Cost recovery & Operation and maintenance cost	E8	115	3,04	10	0,087
	Ability to Pay	E10	128	3,54	6	0,101
Social (0.205)	Access for Water Supply	S1	129	3,58	4	0,102
	Access for Sanitation	S2	129	3,58	5	0,102

By employing this technique, it can be seen that the environmental criteria have a higher weightage (0.301) than other criteria, such as engineering (0.214), economic (0.280), and social (0.205). The fact that this criterion has a higher weightage indicates that it is more crucial in achieving a high sustainability index.

3.3 Enhanced Sustainability Index Model using new Sustainability Parameter Weightage

Each sustainability index such as CWSI, WSSI, WJWSI, WSI, and WPI can easily be enhanced using this new sustainability index parameter weightage, one such example is by enhancing the development of WSSI by Odjegba [46]. The original WSSI model can be seen on equation 14 below:

$$WSSI = \frac{S_{obt}}{MS_{obt}} x\ 100 \quad (14)$$

Where:

S_{obt} = Score obtained from observation.

MS_{obt} = Maximum score obtained from total parameter.

Assisted with new sustainability index parameter weightage, the enhanced WSSI sustainability index can be seen in equation 15 below:

$$WSSI_{eh} = \frac{\sum_i^n P_i \cdot W_i}{\sum_i^n P_{tot} \cdot W_i} x\ 100 \quad (15)$$

$WSSI_{eh}$ = Enhanced WSSI Sustainability Index

P_i = Sustainability Index parameter score obtained from observation, minimum 1 and maximum 5.

W_i = Sustainability Index parameter normalize weightage obtained from Table 3.

P_{tot}= Total Sustainability Index parameter score, maximum score for each parameter is 5.

Using this final form of enhanced WSSI sustainability index, it can reach the original WSSI score from 0 to 100 points.

4. CONCLUSION

The sustainability index has been enhanced using the new sustainability index parameter weightage in this paper. This sustainability index parameter weightage was in general form so it can be applied to the different sustainability indices. Using a leading expert in the water operations questions, the popular sustainability index parameter from CWSI, WSSI, WJWSI, WSI, and WPI was evaluated carefully. The outcome of this evaluation was then computed utilizing the computational intelligence of ANFIS to fit the frequent parameter seen in the other 5 sustainability indices before. The rank and weightage for each indicator and criterion sustainability index parameter can be proposed for engineering 0.214, economics 0.280, social 0.205, and the environment 0.301. It can be concluded that using the suggested method has successfully generated weightage for each sustainability index parameter, thus creating a better water sustainability index.

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