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FUZZY ASSESSMENT FOR WATER QUALITY IN INANAM LIKAS RIVER BASIN, SABAH, EAST OF MALAYSIA

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ABSTRACT

Water Quality Index is an important water assessment that sustain and conserve the aquatic ecosystem. In Malaysia, the current classification practice on Department of Environmental Water Quality Index (DOE WQI) shoes rigid value in term of assessing the input of parameters that close to a class boundary. Hence, this study proposed a technique to assess the parameters in a holistic manner by using the Fuzzy Inference System (FIS). The approach as an assessment tool represents the classes of various ranges and aggregating the parameters using membership function and Centroid Function respectively. A numerical example based on actual data from one of the sampling station from Inanam-Likas River Basin was adapted in this study. It was adapted to demonstrate the proposed approach. Findings shown using the proposed method indicate that the river has poor water status. Overall, FIS is able to assess the parameters and execute into a single index that represent the condition from poor to excellent scales of the water quality.

INTRODUCTION

The beauty of formulating and constructing environmental assessment model with a comprehensive assessment and reliable computational framework of data plays a significant part. Past environmental studies has proved that there are different conditions of ecosystem, variability of subjectivity and uncertainties in the managing the environment as shown by Chen *et al.* (2014), Franz *et al*. (2013), Ocampo-Duque *et al*. (2013) and Gharibi (2012). These groups of international researchers agreed on the presence of subjectivity when it comes to the ecological assessment. The various types of data involve are the linguistic description to describe odor of the river that reflects the dissolved of impurities of the organic compound and the rigid interval on almost all classification of water parameters. Complimentary to facts, the water evaluation can exist in different forms of data; be it in linguistic, interval or even crisp data.

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The existence of different forms of information for the assessment of surface water tends to be complex when it comes to analyze the numerous water variables simultaneously. Due to different forms of data presence in evaluating the quality of the water, researchers had introduced numerous models to integrated the handful of information that they represent the health condition of the river. All of the assessment tools introduced by them had an obvious objective that is to have a single index that reflects the condition of the river. Past researchers had proved the integration of parameters into a single index by using several methods that are promising and scientifically proven. Despite of having different types of water quality models, the most common practice globally was sub-indices techniques adapted from the NSF-WQI (Kumar and Alappat, 2009). Each parameters was weight using experts opinion on the importance of each parameter with respective to the main purpose of the assessment being made. Despite of having the scientifically reliable assessment tools introduced by expertise and researchers, the nature of the assessment tools were identified of having a certain condition or situation for it to work efficiently. Practioners from different countries and its local governments adapted the establish assessment model in their countries because it had been tested for having consistent and reliable test. Undeniably it is scientifically proven and reliable but the assessments constructed were based on various condition. Different methods of interpreting the water data reflect different explanation regarding with the quality of the river. These methods were Delphi method (Almeida *et al.*, 2012), Principal Component Analysis (PCA) (Ji, Dahlgren, and Zhang, 2016; Mustapha and Aris, 2013; Prasanna *et al.*, 2012) and Artificial Neural Networks (Chang *et al.*, 2015) Therefore, the complexity of assessing the water can be managed well by using fuzzy sets theory approach. Fuzzy sets theory was first introduce by Zadeh (1965) and it provides precise frameworks to define any criteria of a certain classes or designated group. One of the Fuzzy's application approaches is Mamdani fuzzy system that is also known as Fuzzy Inference System (FIS).

It uses the If-Then rules that make the model easier to reflect the subjective and complex nature of assessing and managing the river basin. Study done by Carbajal-Hernández *et al*. (2012) introduces a water assessment using reasoning process that highlights the importance of several main factors of shrimp ecosystem. Factors based on the physical, chemical and biological parameters were organized in several groups according to its potential harmful effect towards shrimp organism specifically. The reviewer had adapted two indices from Hydrological water quality Index (HI)c and Canadian Council Ministry of Environment (CCME) into the introduced water assessment alongside with the reasoning process of the possible harmful situation that can happen to the aquatic ecosystem. The findings successfully shown the ability of FIS integrate numerous water parameters into complete water quality index. The idea of using reasoning process to resemble or potray the real scenarios in assessing water was also supported by Ocampo-Duque *et al*. (2013). Several research and findings done by Nikoo (2011), had also distinctly described the reasoning process with different condition implemented in their evaluation process. Indeed, even though there were different factors of fuzziness in any propose system, FIS indeed had proven that the uncertainties and variabilities had been evaluated efficiently.

Water Quality Index (WQI) is an assessment of water that involves local necessity pollution status on the river basin. It was developed by the U.S. National Sanitation Foundation (NSF) for monitoring the quality of water bodies in the U.S. WQI had been implemented in numerous countries including Malaysia (Koçer and Sevgili, 2014). In Malaysia, the Department of Environment (DoE) uses DoE Water Quality Index (DoE WQI) and National Water Quality Standards (NWQS) to assess the quality status of the river. This WQI comprises of 3 main steps. First is determination of weight for each parameter by the experts, secondly is the determination of the quality function through sub-index rating curve and lastly is the calculation for the average of all calculated sub indices to obtain the final value of WQI. Furthermore, each parameter has different formulae for different value of its parameter. The complex analysis of local index can be time consuming and easier for error to occur on sub-index calculation (Gazzaz *et al.,* 2012). Since the formula uses in calculating the WQI was establish in different environment and climate, the formula are less suitable to be implemented in a region that has different climate and environment stress (Abdul Zali *et al.*, 2011). The final of WQI represent the quality of the water and classified according to its uses; water supplies, aquatic organism and irrigation purposes. Overall, the WQI have 5 classes and is in the form of range. The quality of the water then can be classified either as Class 1, Class 2(A) and (B), Class 3, Class 4 and Class 5 (DoE, 2013). Table 1 represents selected parameters that have been classified according to its current classification used by the DoE in Malaysia. Table 2 summarizes the classification of water quality on selected parameters according to DoE WQI and NWQS for Malaysia. Therefore, in this paper we propose a water assessment evaluation using FIS by adapting the current classification of water status from the DoE WQI. To do so, this paper is structured as follows: Section 1 is the introductory of water quality assessment and the review on Fuzzy applications. Section 2 briefly identify and discuss the problems that are being highlighted in this study; Section 3 and 4 both discuss the background theory and implementation of proposed methods for illustration purposes, respectively; and finally, Section 5 concludes the overall findings of the paper.

Table 1. Classification levels for related parameters

Parameter	Classes				
	I	II	III	IV	V
DO (mg/1)**	>7	[5,7]	[3,5]	<3	<1
NH_3N (mg/1)**	<0.1	[0.1,0.3]	[0.3,0.9]	[0.9,2.7]	>2.7
Turbidity (NTU)**	5	50	-	-	-
pH	[6.5,8.5]*	[6,7]	[5,6]	<5	>5

*Index are according to National Water Quality Standards for Malaysia
**Index are according to DoE Water Quality Index Classification

Problem identification

Nowadays, different water quality assessment proposed by international researchers shows that each assessment have their own emphasize based on the water bodies main function. The current range implemented by Department of Environment through DOE-WQI for classification of parameters indexes showed less flexibility in judging the concentration of a parameter that is close to the boundary. Inputs of hydrological data into interval sets of data had shown the uncertainties of inputs in evaluating the data. Uncertainties of inputs can be evaluated effectively by using fuzzy logic in water assessment. Therefore, this paper proposes to assess the water parameter by applying into Fuzzy Inference System to execute the water assessment.

The basic concept and proposed method

Fuzzy Inference Systems

Fuzzy sets theory had been applied in various areas such as in computer science, medicinal field, decision theory, expert systems, logic and management science. This theory can solve various type of problems in different field including environmental problems (Clair and Sinha, 2014; Gharibi *et al*., 2012; Gutiérrez-Estrada *et al.,* 2013). It is because of the human subjectivity involves in judging and interpreting the environment. The complexity of managing the ecosystem of a river can be managed well by fuzzy sets theory, which is to solve any fuzzy and complex information in a comprehensive manner. Hydrology data exist in a crisp data and being classified into certain range respective to its parameter.

Every classification of the parameters with regards to its possible class were represented using membership functions. A membership functions (μ) transforms the real value obtained

Table 2. Water classes and uses

Class	Uses
Class I	Conservation of natural environment. Water Supply - Practically no treatment necessary. Fishery - Very sensitive aquatic species.
Class II	Conventional treatment required Fishery - Sensitive aquatic species Recreational use with body contact
Class III	Water supply - Extensive treatment required. Fishery – Common, of economic value and tolerant species; livestock drinking
Class IV	Irrigation
Class V	None of the above

Table 3. Membership parameters with respective to each water parameters

Parameters	Classification	*a*	*b*	*c*	*d*
DO (mg/1)	Class 1	6	7	50	50
	Class 2	4	4	7	8
	Class 3	2	3	5	6
	Class 4	0	1	3	4
	Class 5	0	0	1	2
NH_3N (mg/1)	Class 1	0	0	0.1	0.2
	Class 2	0	0.1	0.3	0.4
	Class 3	0.2	0.3	0.9	1.0
	Class 4	0.8	0.9	2.7	2.8
	Class 5	2.6	2.7	50	50
Turbidity (NTU)	Class 1	0	5	50	50
	Class 2	50	50	150	150
	Class 3	*na*	*na*	*na*	*na*
	Class 4	*na*	*na*	*na*	*na*
	Class 5	*na*	*na*	*na*	*na*
pH	Class 1	5.5	6.5	8.5	9.5
	Class 2	5	6	7	8
	Class 3	4	5	6	7
	Class 4	0	0	5	6
	Class 5	4	5	14	14

na= not available

The existence of interval data in classifying the water quality shows the existence of subjectivity in the classification process. Similarly Fuzzy Inference System (FIS) has been an effective and holistic tool to evaluate and execute any forms of subjective data into a single output. In this paper, the current water quality classification will be adapted into FIS for the execution of water status. The constructed outcome from the propose analysis was Excellent, Very Good, Good, Moderately Poor and Poor. Counter back strategy implemented in this paper to solve the evaluation of data on the boundary of a range was resolve as well by using FIS. That is to say, FIS is a process of formulating a mapping from a given multiple input to a single output using fuzzy logic. The process of fuzzy inference involves three important concepts: membership function, logical operations and If – Then rules (Carbajal-Hernández *et al.,* 2012; Ocampo-Duque *et al.,* 2013).

Proposed Methods of Fuzzy Inference System into Water Quality Assessment

Step 1: Fuzzy inputs

This paper proposes the uses the inputs of hydrology data into the membership functions as the first steps. It was implemented in the inputs of the FIS as membership functions.

into a [0,1] value. Methods used to determine the membership function was from the literature review from previous study. Trapezoidal membership functions (TrapMFs) define the input transformation of the FIS and were represented as in expression (1).

$$\mu(x,a,b,c,d) = \min\{\frac{x-a}{b-a},1,\frac{d-x}{d-c}\} \quad (1)$$

Where x is a water quality variable; a, b, c and d are membership parameters. Table 3 shows the value of each membership parameters to be adapted into expression (1).

Figure 1 shows the representation of classification of Dissolved Oxygen (DO), ammoniacal nitrogen (NH_3N), pH and turbidity in TrapMFs. Figure 2 shows the representation of Water Quality Index in TrapMFs. The constructed TrapMFs was adapted from the DoE WQI that was still used in Malaysia.

Step 2: Fuzzy Operators

The membership degree of each part of rule antecedent is computed after the inputs are fuzzified. Three fuzzy operators as had shown in expression (2), (3) and (4) were used. The operators are union (OR), intersection (AND) and negation (NOT).

Union (OR)	$\mu_{A\cup S}(x) = \max\{\mu_A(x)\mu_y(x)\}$	(2)
Intersection (AND)	$\mu_{A\cap S}(x) = \min\{\mu_A(x)\mu_y(x)\}$	(3)
Negation (NOT)	$\mu_A(x) = 1 - \mu_A(x)$	(4)

Step 3: Inference Rules (reasoning Process)

Subjectivity may refer to the specific interpretations of any aspect of experiences. Likewise in this paper, it refers to the possibilities of the crisp data input in the classification of data in the forms of interval set used in evaluating the water.

As reported in the annual report of Department of Environment (2014), water experts' uses linguistic expression such as Class 1, Class 2, Class 3, Class 4 and Class 5 to represent the status of the water. The sets of classification constructed used in this paper were described.

Dissolved Oxygen	=	DO	=	{Class 1, Class 2, Class 3, Class 4, Class 5}	=	*{C1,C2,C3,C4,C5}*
Ammoniacal Nitrogen	=	NH_3N	=	{Class 1, Class 2, Class 3, Class 4, Class 5}	=	*{C1,C2,C3,C4,C5}*
pH	=	pH	=	{Class 1, Class 2, Class 3, Class 4, Class 5}	=	*{C1,C2,C3,C4,C5}*
Turbidity	=	Turb	=	{Class 1, Class 2}	=	*{C1,C2}*

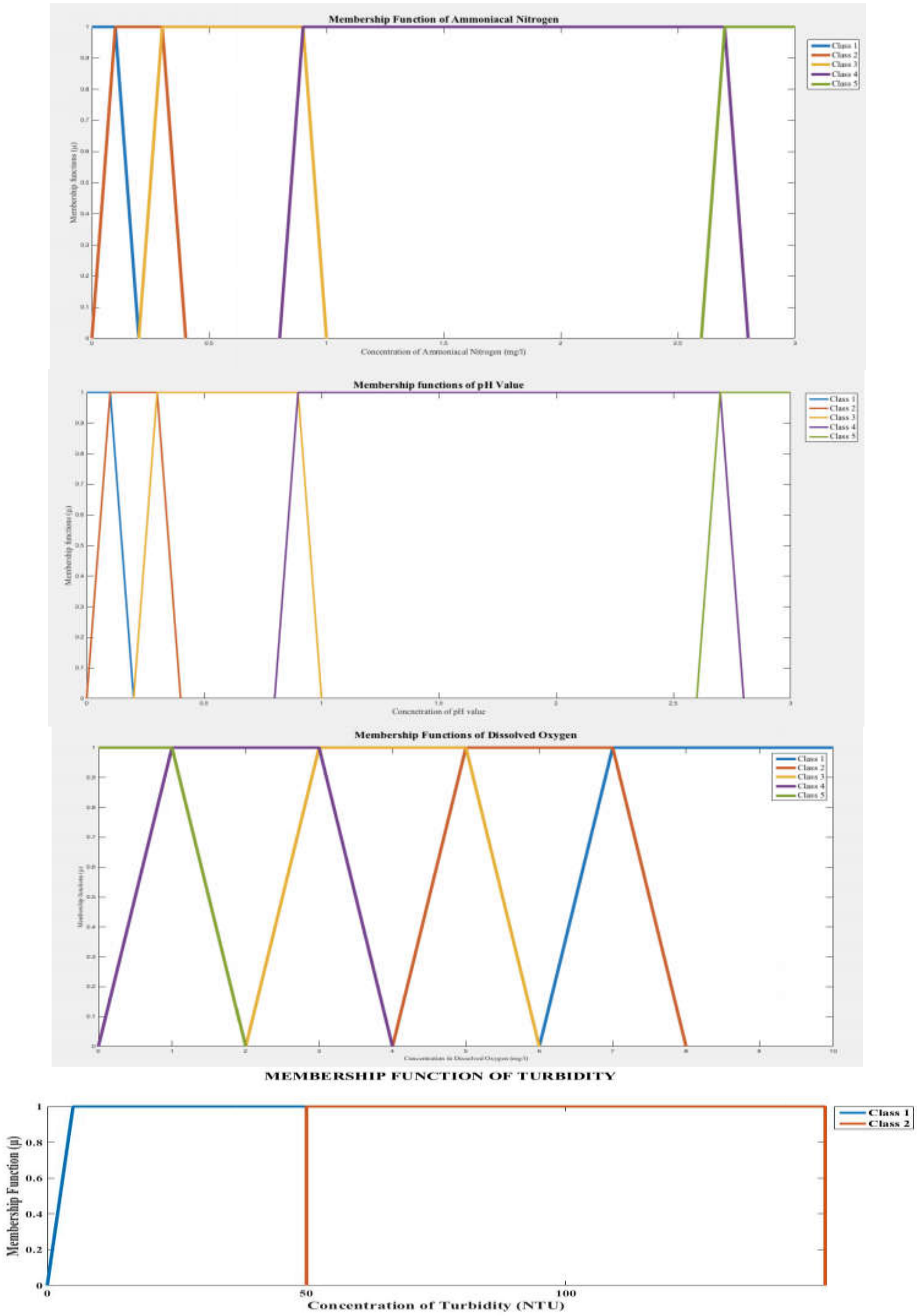

Figure 1. Membership functions for water parameters: Dissolved Oxygen, Ammoniacal Nitrogen, pH and Turbidity

The terms representing each set have the following meaning: *C1* as Class 1, *C2* as Class 2, *C3* as Class 3, *C4* as Class 4 and *C5* as Class 5. As an illustration of application on River A, if the dissolved oxygen (DO) in the water is Class 1, the ammoniacal nitrogen (NH_3N) level is Class 1, the pH is Class 1 and the level of turbidity is Class 1, then the expected water quality is excellent. These linguistic forms of information can be interpreted into fuzzy language. The robustness of the systems also depends on the number and quality of the rules constructed for the evaluation using FIS. As demonstrated in this paper, there were 250 rules constructed and it reflects the possible inputs of the total parameter involve in the assessment. To illustrate some of the sets constructed to represent the parameters used in this paper, the first 6^{th} rules and the 250^{th} rules were described as follows.

Rules 1

If DO is *C1* and NH_3N is *C1* and pH is *C1* and Turb is *C1* then WQI is *Excellent.*

Rules 2

If DO is *C1* and NH_3N is *C1* and pH is *C1* and Turb is *C2* then WQI is *Excellent.*

Rules 3

If DO is *C1* and NH_3N is *C2* and pH is *C1* and Turb is *C1* then WQI is *Excellent.*

Rules 4

If DO is *C1* and NH_3N is *C2* and pH is *C1* and Turb is *C2* then WQI is *Very Good.*

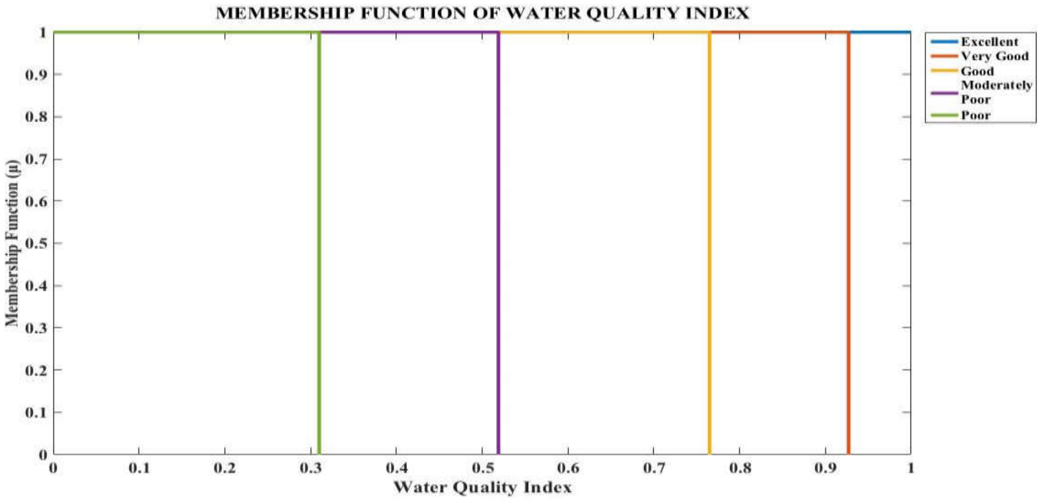

Figure 2. membership functions for Water Quality Index

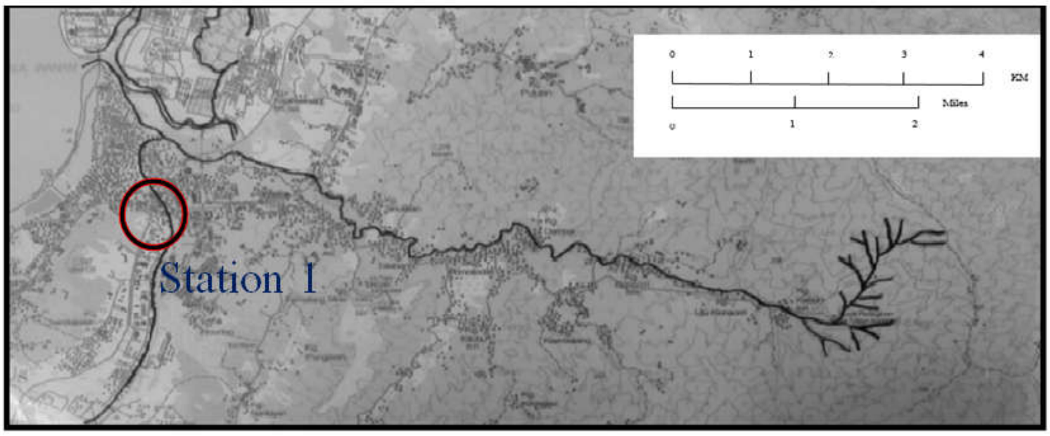

Figure 3. Inanam Likas River Basin, Sabah

Table 4. Concentration of selected parameters in Inanam River on 15 July 2015

Location of water sampling	GPS Location	Parameters			
		pH	DO(mg/1)	NH_3N(mg/1)	Turbidity(NTU)
Kolombong Industrial Area	05º 59.354'N 116º 07.250' E	8.84 *(8.82-8.87)	1.347 *(1.26-1.42)	0.673 *(0.56-0.83)	643.667 *(593-717)

*Average range of each parameters

Rules 5

If DO is *C1* and NH_3N is *C3* and pH is *C1* and Turb is *C1* then WQI is *Excellent.*

Rules 6

If DO is *C1* and NH_3N is *C3* and pH is *C1* and Turb is *C2* then WQI is *Excellent.*

"……………….."

Rules 250

If DO is *C5* and NH_3N is *C5* and pH is *C5* and Turb is *C5* then WQI is *Poor.*

The output fuzzy rule then computed using the fuzzy operator and,

$$\mu_R = \min\{\mu^i_{DO}, \mu^j_{NH_3N}, \mu^k_{pH}, \mu^l_{Turb}\} \tag{5}$$

Where *i, j, k* and *l* are the different levels of concentration (Class 1, Class 2, Class 3, Class 4, Class 5 respectively) depends on each parameters.

Step 4: Aggregation

The membership function will be aggregated and produce a single output after the being used different set of rules and being matched with fuzzy outputs (μ_N). The combination of the rules is called aggregation. The aggregation used to fuzzy union all output in the FIS is the maximum methods (Carbajal-Hernandez *et al*., 2012).

Step 5: Defuzzification

Next, the different water quality condition obtained in a graph will have be obtained. Centroid function (CF) returns the center of area under the curved formed by the output fuzzy function according to expression 6:

$$CF = \frac{\int x\,\mu_{out}(x)dx}{\int \mu_{out}(x)dx} \tag{6}$$

The output of the center of area by centroid function determines the input value to be classified into the classification of water status from Poor to Excellent accordingly. The different water quality status from poor to excellent can be within this range and normalization of results was done using expression 7. The output value of the final evaluation was in the range of [0,1].

$$WQI = \frac{CF - \min(CF)}{\max(CF) - \min(CF)} \tag{7}$$

Study Area

Inanam-Likas River basin is one of the major river in the district of Kota Kinabalu, Sabah at East of Malaysia. With the total human population of 203,346 covers Inanam and Kota Kinabalu district, the river receives extensive urban and industrial domestic waste discharges as well as surface runoff. Inanam-Likas River Basin has been chosen as the sample location because of the rapid urbanization and industry growth. Countless of factories, workshop, large residential area, villages, Village Community clinic, religious buildings, recreational park and two schools are located along the river. Human activities such as living livestock, factories and workshops are several strong potential sources to emit chemical substances to its surrounding through runoff and soil. With the diversity of population background and activities, Inanam-Likas river basin is very well suited in representing an ecosystem of a river that is involved with the human population and the aquatic organisms. Figure 3 shows the outline of Inanam-Likas River Basin and station 1 is one of the sampling sites. It represents the industrial activity done along the river.

Implementation and Discussion

To demonstrate our proposed method applied, we adapted one of our water quality data taken form Inanam River, Sabah. The data was tabulated in Table 4. Given a situation that obeys the rule constructed in Rule 196, 197, 198 and Rule 199, having their parameters DO, NH_3N, pH and Turbidity and their values of 1.347 mgl^{-1}, 0.673 mgl^{-1}, 8.84 mgl^{-1}, and 643.667 NTU respectively. Using the propose methods stated in expression (1) until (7), the water quality index can be evaluate using the FIS. The execution of assessment was computed using Matlab 2015b as had shown in Figure 3. Based on the calculation computed using the data taken, the river in Inanam Likas River at the specified location was 0.231 and it was classified as Poor. It is indicates the river was at it worst water quality. As reflected in Table 2, Class 5 of water status was not suitable as habitat for the aquatic ecosystem and utilize by humans. Poor condition of the river shows that the river is unhealthy. It affects the food web and the natural function of the river (Aweng *et al.,* 2011). Even though the numerical example only implies only on four-selected parameters, the expected results can be derived using other parameters as long as the representing the range of parameters involves is adapted into the TrapMFs.

Conclusion

In this paper, we have applied the Fuzzy Inference System (FIS) to evaluate the water assessment by using our own hydrological data obtained from the Kolombong Industrial area. It is clearly seen that the proposed method are capable to evaluate the status of the water and the process are less complex and straightforward. Furthermore, this reduces the time required to analyze the hydrological data to determine the status of the water. In short, FIS have shown to be one of the effective and less complex tools to assess the quality of water in a river basin. In the future, the proposed method can be validated using Sensitivity Analysis.

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