Detention Pond Phosphorus Loadings Uncertainty Using Fuzzy Logic

Supiah Shamsudin, AzmiAb Rahman, Zaiton Haron, Anieziatun Aqmal Puteh Ahmad

Abstract—This study vitalized the uncertainty and fuzzy rules consideration in the estimation of phosphorus loadings and eutrophication status of the hydrologic system namely detention pond using Fuzzy Logic (MATLAB). These methods were chosen to cater for the uncertainty of loading factors such as sediment and phosphorus inflow, inflowing discharge and pond storage volume. The average of phosphorus concentrations obtained from site investigation was 0.178 mg/L, hydraulic residence time was 1.77 year and the average annual hydraulic loadings was 694.70 m/yr, obtained based on the 12 years period (2000-2012). The results showed that the maximum and minimum of phosphorus loadings was 2.00 x 10-3 ton/year and 5.00 x 10-3 ton/year. Phosphorus loadings obtained from MATLAB fuzzy logic was 3.9 x 10-3 ton/year. The eutrophication status of the detention pond was investigated using Fuzzy Logic Approach, incorporating various fuzzy rules (MATLAB). This evaluation required the twinning usage of Vollenweider P-Loadings diagram. Generally, eutrophication status in the detention pond at KolamTadahan UTM was still considered Oligotrophic stage. However precautions need to be established as the pond are alarmingly approaching the Eutrophic Status.

Keywords—Detention Pond, Phosphorus loadings, Eutrophication, MATLAB Fuzzy Logic, Uncertainty.

I. INTRODUCTION

Phosphorus (P), nitrates and sediments inflows can cause eutrophication or lakes and ponds . This aging process causes growth of algae or other vegetation, depletion of dissolved oxygen, increased turbidity and a degradation of water quality. Pollutants like suspended solids accumulate over time thereby these solids should be periodically removed (Davis and McCuen, 2005). Yang et.al (2008) claims that once a water body is eutrophicated, it will lose its primary functions and subsequently influence sustainable development of economy and society. Predicting thesediment inflow into a detention, its deposition and its accumulation throughout the years have been an important problems in hydraulic engineering (Salas, 1999). Sediment accumulation and detention estimation ordinarily experience uncertainties in their analysis either through empirical or analytical approaches (Salas, 1999).

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Literature reviewed so far showed that the lacking of uncertainty and fuzzy rules venture in detention pond pollutant loadings and eutrophication status. This study venture the uncertainty aspects due to vagueness of many hydrological variables such as runoff inflowing dischargeshydraulics loadings, sediment phosphorus inflow, and pond storage volume.

Several uncertainty analysis developed and applied in water resources engineering so far include Monte Carlo simulation (MCS) such as by Yen et al. 1986. Fuzzy uncertainty analysis include by Chang and Chen (2001); Supiah and Noor Baharim (2006); and Supiahet. al. (2011). Other Fuzzy hydrologic studies include rainfall–runoff modelling studies such as carried out by (Shamseldin, 1997) and (Giustolisi and Laucelli, 2005), streamflow prediction (Chang and Chen, 2001), (Kisi, 2004a), reservoir inflow forecasting (Bae et al., 2007), and suspended sediment estimation (Cigizoglu, 2004) and (Kisi, 2004b). Kisi (2004c) developed fuzzy models to estimate daily suspended sediments. Lohani et al. (2007) used fuzzy logic for deriving stage-discharge sediment concentration relationships. They used a fuzzy system based on Tagaki-Sugeno technique and subtractive clustering approach for the derivation of the membership functions. These literature reviews indicated that the detention pond fuzzy approach related was still not adequately adventured or investigated. Therefore this study initiated the investigation of detention pond uncertainty using MATLAB fuzzy logic. The objectives of this study are as follows:

1) To estimate the long term phosphorus loadings rates in the detention pond using Vollenweider model.
2) To apply the MATLAB Fuzzy Logic Toolbox as an approach for eutrophication status evaluation.
3) To demonstrate the uncertainty of phosphorus loadings rates using MATLAB Fuzzy Logic Simulation.

II. METHODS

A. Site Description

KolamTahanan 1 is located within UniversitiTeknologi Malaysia (UTM) south branch campus, Skudai (Figure 1). The catchment area of UTM area is about 11 km^2 (2718.16 acre) and it separated into 10 sub basins. This catchment has 9 mini dams as temporary storage and release of runoff for flood control. This study focused on detention pond at sub basin 1 (KolamTahanan 1). Fifteen water samples were taken from site and tested at the UTM Environmental Laboratory for phosphorus concentration and other water quality parameters. Rainfall data (2000-2012) are obtained from Drainage and Irrigation Department (DID), Ampang, Malaysia.

B. Phosphorus Loadings Estimation Related Models

The phosphorus loadings were estimated using the most practical model developed by Vollenweider(1969). He developed a statistical relationship between phosphorus concentration and hydraulic residence time (HRT) to predict lake area annual phosphorus loadings (Schnoor, 1996). The critical hydrological variable such as runoff inflowing discharges, hydraulicsloadings and pond storage volume estimation were refined using IHACRES model .

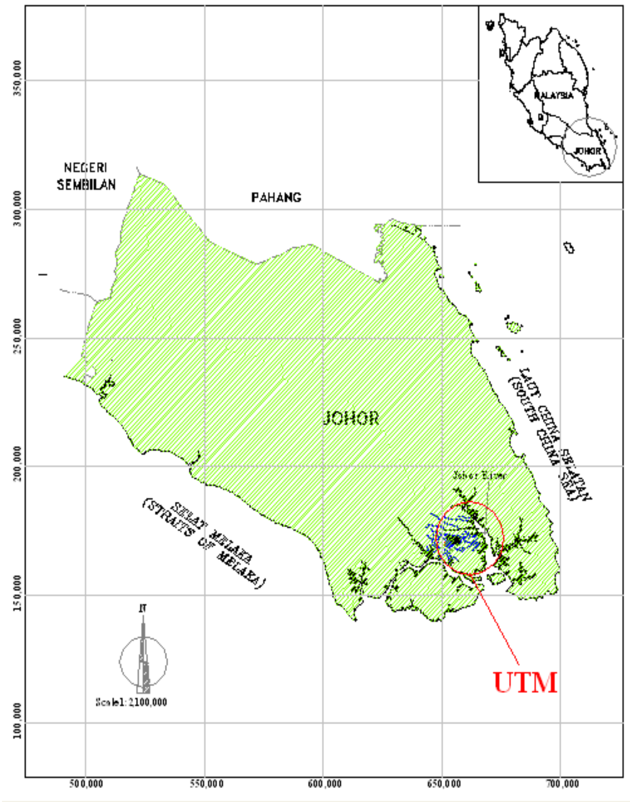

Fig. 1: Detention Pond (KolamTahanan 1) at Universiti Teknologi Malaysia (UTM) , Southern Malaysia

Detention Pond 1 is located betweenDesaBakti and PusatKesihatanUniversitiTeknologi Malaysia (UTM), Skudai, Southern Malaysia. The area of this pond (KolamTahanan 1) is 13607 m^2 (3.36 acre) and the maximum width and maximum length are 106 m and 208.8 m respectively.KolamTahanan functions as flood control and recreational activities such as kayaking. It also provides an aesthetic value and preserves the habitat of aquatic life.

C. Annual Hydraulic Loadings- IHACRES model

IHACRES (Identification of unit Hydrographs and Component flows from Rainfalls, Evaporation and Streamflow data). was developed collaboratively by Institute of Hydrology in United Kingdom and the Centre for Resource and Environmental Studies of Australian National University in Canberra (2001)

D. MATLAB Fuzzy Logic Software

The Fuzzy Logic tool introduced in 1965 by LotfiZadeh was applied in this stduy. It is a mathematical tool for dealing with uncertainty and grants a technique to deal with vagueness and information granularity. Fuzzy Interface System (FIS) Editor, Membership Function Editor, Rule Editor, Rule Viewer, Surface Viewer were useful menu for the analysis.

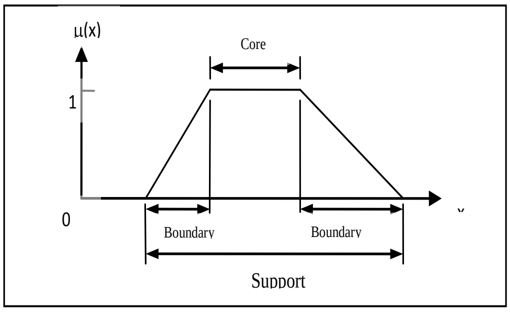

Fig 2: General feature of fuzzy membership function

The fuzzy logic approach basically was developed from conceptualizing and analyzing fuzzy membership function diagram (Figure 2).

III. METHODS

A. Data collection

Fifteen water samples were taken from the three site visits at study area using the water sampler simple equipment. The water samples were tested at the UTM Environmental Laboratory to obtain the phosphorus concentration levels. The average phosphorus content was 0.178 mg/L. The highest phosphorus content recorded was 0.36 mg/L at Station 4 on the second visit. The lowest concentration which was 0.070 mg/L also obtained at Station 4 near the outlet.

Annual hydraulic loadings, qs is a parameter in Vollenweider Model which consists of other parameters such as 12 year rainfall data from year 2000 until 2012, annual runoff coefficient, C and drainage area. Average hydraulic loadings during the 12 years period obtained was 694.70 m/year while the hydraulic residence time was 1.77 year. Inflow total phosphorus concentration was 63.73 ppb based on Vollenweider formula.

B. Modeledlresults with IHACRES model

The rainfall and temperature data applied are from 2000 to 2010. The observed streamflow was approximated and compared using the storage equation. Figure 3 showed the modeled and calibrated streamflow, Table 1 and Table 2 showed the calibration parameters. The highest modeled streamflow was 234.35m3/s in 2006. The lowest streamflow or baseflow was 4 m3/s. The largest bias was -1.2157 mm/day and the smallest bias was -0.0265 mm/day. These values were closed to zero and therefore was acceptable. The highest R2 value was 0.9204 while the lowest was 0.7813. R2 value nearer to 1 indicates the better performance of the model. Both statistics showed that the model was able to perform well.

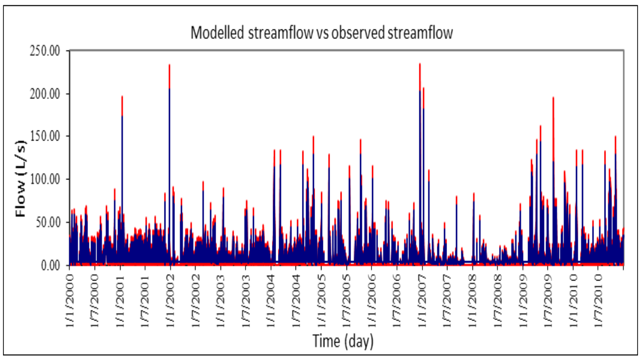

Fig. 3: ModelledStreamflowvs Observed Streamflow

Table I.Non linear model module calibration result

mass balance term (c)	0.7017
drying rate at reference temperature (tw)	15.0000
temperature dependence of drying rate (f)	4.0000
reference temperature (tref)	43.0000
moisture threshold for producing flow (l)	0.0000
power on soil moisture (p)	0.0200

Table II. Linear model module

Recession rate 1 ($\alpha^{(s)}$)	-0.050
Peak response 1 ($\beta^{(s)}$)	0.950
Time constant 1 ($\tau^{(s)}$)	0.333
Volume proportion 1 ($v^{(s)}$)	1.000

C. Fuzzy Logic approach for eutrophication status evaluation

The Fuzzy Interface System (FIS) editor in the Fuzzy Logic toolbox was updated from the default to reflect the new names of the input and output variables known as PPB and HRT for inputs and Trophic State for output. PPB represented the inflow total phosphorus concentration in unit of Part Per Billion while HRT was the Hydraulic Residence Time in unit of year. Workspace variable was named as Eutrophication (Figure 4). The input PPB range was redefined as 0 to 1000, input into the Range box meanwhile input HRT was input as 0 to 100. The range for the output was 0 to 1. The rules were defined after the variables have been named and identified. The fuzzy membership functions (MFs) have appropriate shapes and names in the Rule Editor. The fuzzy membership function editor was created for each variable in triangular MFs. These 16 rules was created and developed based on Vollenweider P-loadings diagram (Figure 5 and 6).

The fuzzy membership function and rules were set up for each variables, trophic state was defined by entering the value of PPB and HRT as [63.73 1.77] in Rule viewer (Figure 5).These values of PPB and HRT was obtained from Vollenweider(1969). The first two columns of plots which are the two yellow plots show the membership functions referenced by the antecedent or the if-part of each rule. The third column of plots on the first plot shows the membership functions referenced by the consequent or the then-part of rule. The output Trophic Index was displayed as 0.211 in third column. This value based on Vollenweider P-loadings diagram indicated that KolamTahanan 1 is in Oligotrophic state. Phosphorus loadings of 3.9 x 10-3 ton / year was estimated from Algorithms in Vollenweider(1969).

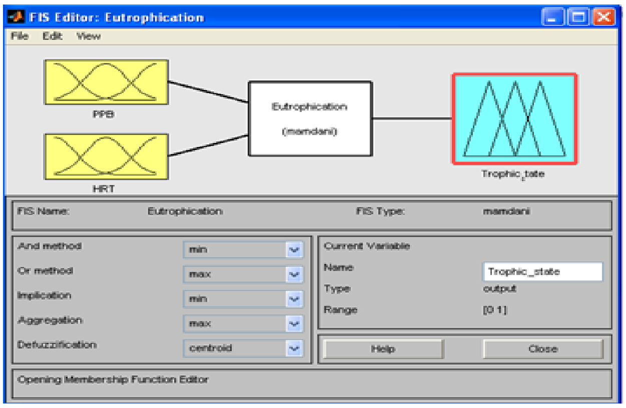

Fig. 4: FIS editor interface

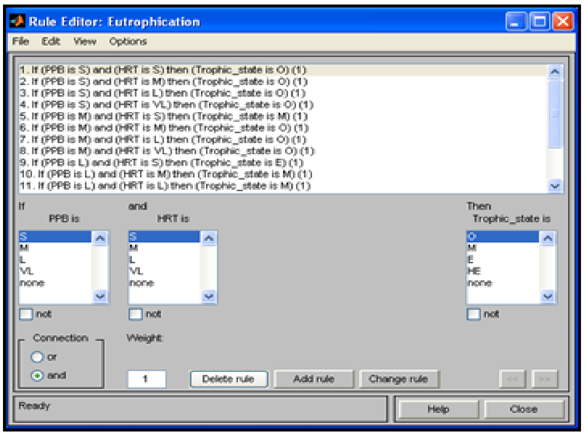

Fig. 5: Rule editor interface

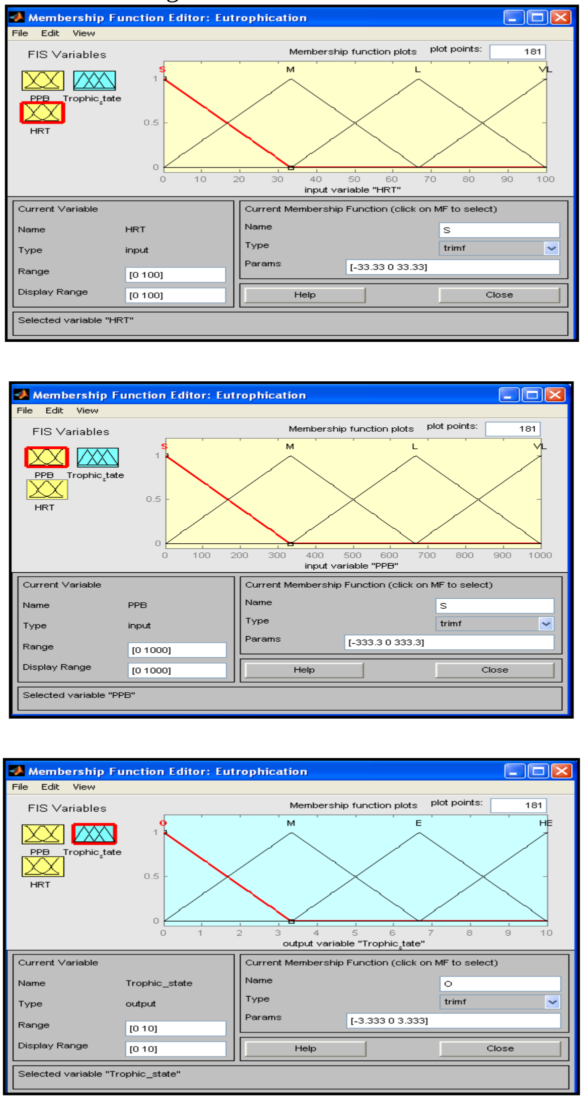

Fig. 6 : Membership function editor interface

IV. CONCLUSIONS

The eutrophication status of the detention pond was investigated using Fuzzy Logic Approach, incorporating various fuzzy rules (MATLAB). This system consists incorporates the two inputs and one output based of the Vollenweider P-loading model parameters. PPB was used to represent the inflow total phosphorus concentration in the unit of part per billion and HRT as hydraulic residence time in the unit of year. Trophic state has been produce from these inputs. Uncertainty analysis using the MATLAB fuzzy logic was demonstrated in this study.

The study revealed that:

1) Eutrophication status at KolamTadahan 1, UTM, Malaysia was considered as Oligotrophic stage based on Vollenweider P-Loadings and Fuzzy Rules.
2) The annual hydraulic loadings of 694.70 m/year in 12 years period was predicted by using peak flow rate formula.
3) Phosphorus loadings obtained from MATLAB fuzzy logic was 3.9 x 10^{-3} ton/year .

However the lake must be properly maintain and conserve to keep up with the eutrophication status. The Phosphorus inflows may be reduced using several treatment should to aluminum sulfate (alum) (Rodriguez, I. R et al., 2008) and periphyton on submerged artificial substrata (Jobgen, A. M. et al., 2004

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