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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Supiah Shamsudin, Razak School of Engineering and Advance Technology, UniversitiTeknologi Malaysia, International Campus, 54100, Kuala Lumpur, Malaysia.

AzmiAb Rahman, Perdana School of Science Technology and Innovation (STI) Policy, UniversitiTeknologi Malaysia, International Campus, 54100, Kuala Lumpur, Malaysia.

Zaiton Haron, Faculty of Civil Engr, UniversitiTeknologi Malaysia, 81310 UTM Skudai, Malaysia.

Anieziatun Aqmal Puteh Ahmad, Faculty of Civil Engr, UniversitiTeknologi Malaysia, 81310 UTM Skudai, Malaysia.

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 .

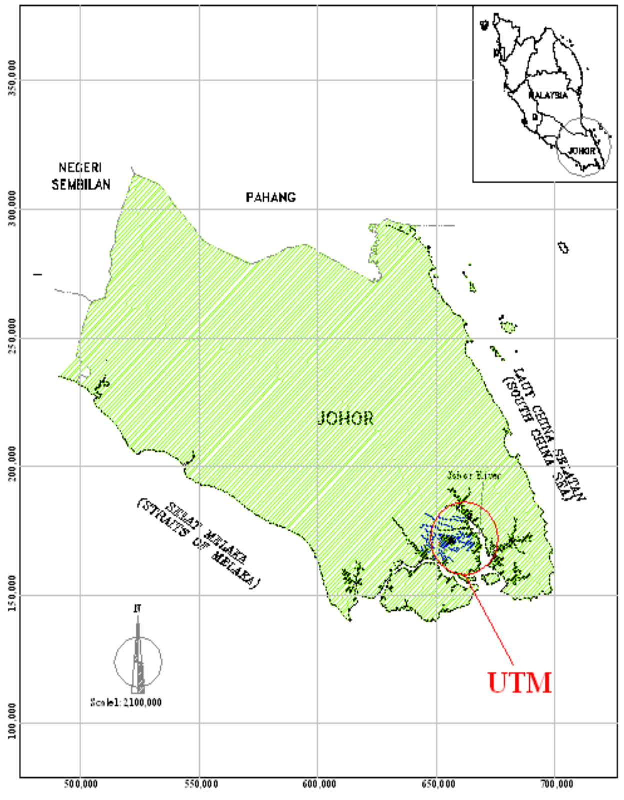

Fig. 1: Detention Pond (KolamTahanan 1) at Universiti Teknologi Malaysia (UTM) , Southern Malaysia

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.

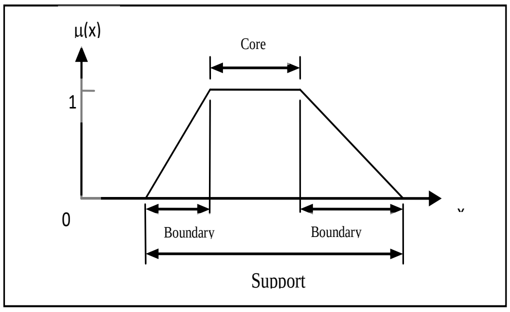

Fig 2: General feature of fuzzy membership function

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.

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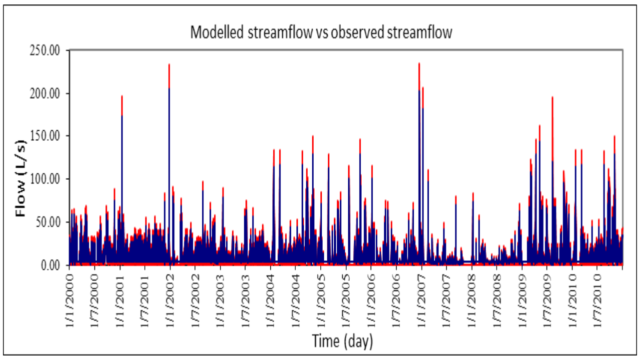


Fig. 3: ModelledStreamflowvs Observed Streamflow

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).

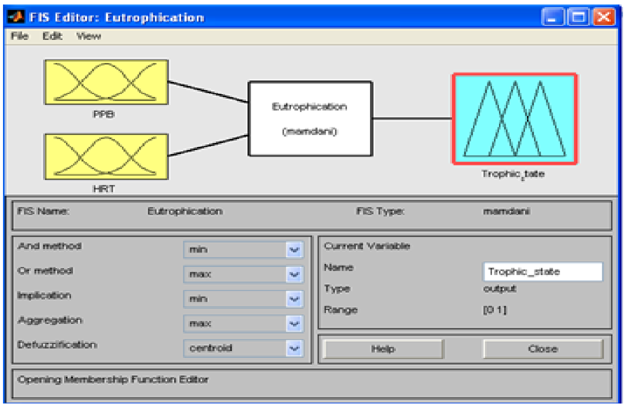


Fig. 4: FIS editor interface

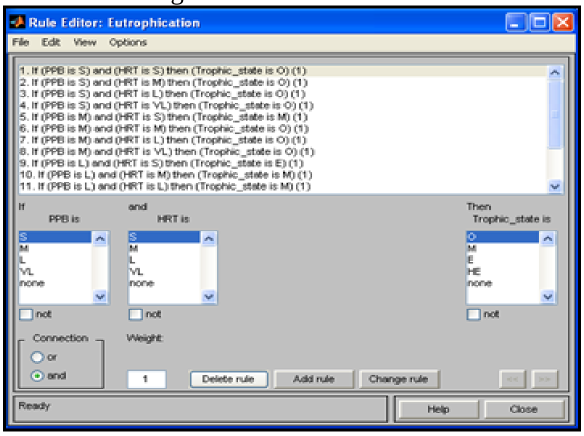
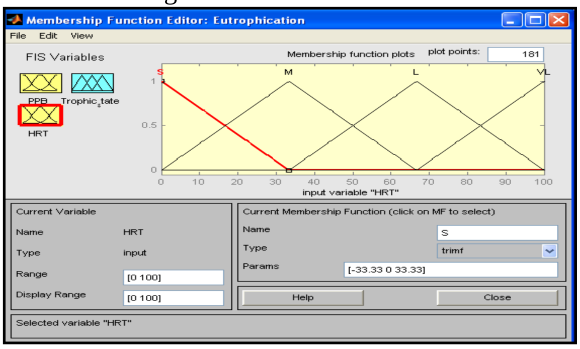
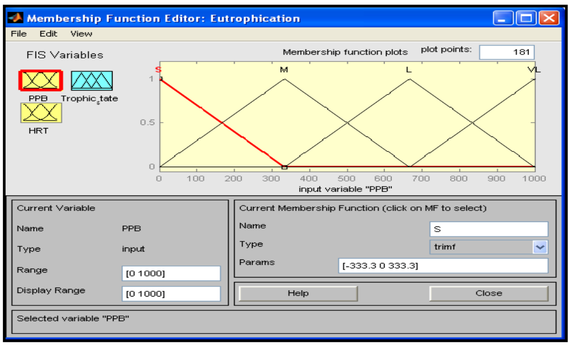


Fig. 5: Rule editor interface





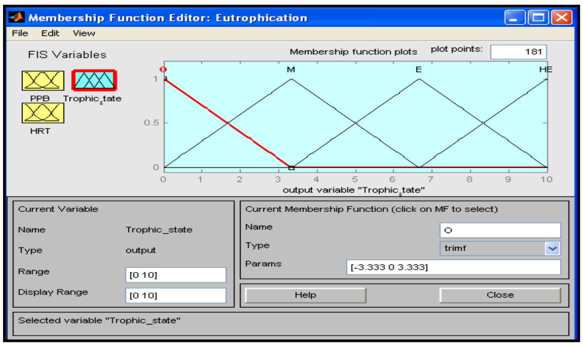


Fig. 6 : Membership function editor interface

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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DrSupiahShamsudin is an Associate Professor in the Water Resources and Hydrology area at the Department of Civil Engineering, Razak School of Engineering and Advanced Technology, UTM-IC, Malaysia. Her main specialization in particular is Impounded Water Bodies MultiObjective Engineering. The researches interests include intelligent detention pond design, watershed and reservoir management under uncertain environment, environmental hydrology, reservoir eutrophication, fuzzy & risk related approaches and multicriteria decision support for water resources systems. She had publish**17** papers. She is a member of International Water Association (IWA) London, Graduate Engineer for Board of Engineer Malaysia (BEM), International Association Hydrological Sciences (IAHS), International Association of Environmental Hydrology (IAEH), Malaysian Hydrological Society (MHS), Malaysian Water Association (MWA) and Malaysian Nano Association (MNA). She was awarded with AnugerahKualitiFakultiKejuruteraanAwam 2009, Silver Award for Invention/Innovation of "Construction Noise Modelling using Stochastic Approach" in I4th Industrial Art Technology Exhibition (INATEX) 2012, Supervisor for 'UTM Post Graduate (PhD) Best Student Award' – 49th Convocation, UniversitiTeknologi Malaysia, Skudai, 2012, AnugerahPerkhidmatanCemerlang UTM for 2010 and 2005, Supervisor for 'Gold Medal Best Thesis Award' – Malaysia World Water Day, 2009, AnugerahJasaBakti, UniversitiTeknologi Malaysia, Skudai, Johor, 2003, Diploma of Academic Excellent – Civil Engineering Honor Society University of Miami, Florida, USA, (1981) and Biasiswa Skim LatihanAkademikUniversitiTeknologi Malaysia for 1998 and 1990.

She also has patent pending for Predicting Uncertainty of Sediment Loads, Jun 2010 and Fuzzy Approach to Forecast Phosphorus Loadings, December 2009. She wrote five books which are Uncertainty of Phosphorus Loadings Estimation Using Vollenweider Model For Reservoir Euthrophication Control, Self- Assessment Report for Accreditation of an Engineering Program, Structure For Architects and note book for 'Introduction to Hydrology and Introduction to Fluid Mechanics.

DrAzmi Bin Ab. Rahman is a lecturer at the Department of Management, Faculty of Management and Human Resource Development, UTM, Skudai, Johor, Malaysia. The researches interests include A study on Government Intervention, Factor Endowments, Intermediate Inputs and Foreign Direct Investment in ASEAN Countries, Income Distribution and The Role of Institutional Structures, Phosphorous Loadings Estimation into Layang Reservoir and Sediment Yield Estimation Using MUSLE. Case Study: Layang Reservoir. He took part in national consultancy regarding Industrial Training Schemes Study, General Business Environment, Research Methods, Trade facilitation Program the Malaysian Experiences, Market Impact of the Jaya Jusco Activities on Johor Jaya Area, Market Impact of the Jaya Jusco Activities on Taman Universiti Area, Economic Impact Study for the Construction of An Alternative Bridge Across Permas Jaya Bridge in Johor Bahru, Environmental Economic of the Construction of the UluJelai Hydroelectric Facility and Economic Impact of Gated Community Living on the Neighboring Communities. He had publish nine papers for international, national and faculty publication. He also published three books which are Trade Policy, Taxes and Foreign Direct Investment in ASEAN, A Study on Government Intervention, Factor Endowments, Intermediate Inputs and Foreign Direct Investment in ASEAN Countries and A study on Income Distribution and The Role of Institutional Structures. His two journals are Technological Capability of the Mold and Die Industry: Development of Research Instrument and Contract and its Effect on the Mode of Production.

Dr.ZaitonBintiHaron is lecterur at Department of Structures and Materials, Faculty of Civil Engineering, UniversitiTeknologi Malaysia. She was graduated from University of Liverpool, UK (Dec 2002-Dec 2006), Master of Science, UniversitiTeknologi Malaysia (1993) and Bachelor of Civil Engineering ,UniversitiTeknologi Malaysia(1988). She had experience for teaching in the past 12 years and the contribution in term of teaching is on Undergraduate and Diploma level. Subjects that she taught/teach are Theory of Structures, Civil engineering drawing, Static, Strength of Materials, Design of reinforced concrete structures, Civil engineering materials and Research Methodology. She is a member of a Panel evaluating Masters Project Presentation and member of a Panel evaluating Master (research) and member of a panel of Scrap book completion in collaboration of 50th Independence Day. She also is a member of ISO PengajarandanPembelajaran ,Alumni UTM , Alumni of University of Liverpool and Working Committee for Annisaa Liverpool 2004 and Member of Malay Speaking Circle (MSC) Liverpool, UK. She also is a professional talk and among her talk are KolokiumJabatan "Probabilistics techniques in acoustics" Jabatan Srukturdan Bahan Fakulti KejuruteraanAwam 2007, World Food Exhibition " Malaysian Food" Everton Childhood Centre,Liverpool and Academic Discourse "Viva Preparation" for Malay Speaking Circle,Liverpool. For publication field she was writing two book and five journal/bulletins such as Stochastic Modelling in Environmental and Building Acoustics, Journal of Recent Research Development Sound and Vibration, Transworld Network, 2(2004), 213-234 ISBN:81-7895-119-3. She also had five paper for International conference and two for national paper. One of her international paper is "The Application of Stochastic Modelling to the Prediction of Noise from Open Sites Activities", Proceeding Managing noise and uncertainties Le Mans 2005. For her research she had four research projects and one of his is Research Project 78252 : "The study of noise from construction sites", Sept 2007-Sept 2009 Sponsor : FRGS Ministry of Higher Education (MOHE). She was awarded with MOSTI (scholarship)–PhD in acoustics 2002, Certificate of environmental noise measurement UK 2003 and Outstanding and among best work presented in International Congress on Acoustics, Madrid 2007.