ORGANIC POLLUTANTS AND HEAVY METALS TRANSPORT IN THE LOWER CHAOPHRAYA BASIN USING SWAT MODEL

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Abstract- The organic pollutants and heavy metals contaminated in the river have been increasingly concerned due to environmental impact, and their high toxicity effects on human health. The raw water that is required for the water supply system in Bangkok generally comes from the Chao Phraya River. In case of the water quality in the Chao Phraya River is poor due to high concentrations of those contaminants affect to the water treatment cost will be increased leading to adversely effects on all water consumers. Water quality analysis in laboratory is expensive and taken much more time. The correct model assessment is worth way to evaluate water quality in the water body for reducing water sampling points. Model development for organic pollutants and heavy metals transport assessment in the Lower Chao Phraya River is important to predict environmental impact which may occurs in the future and helpful to prepare resolution of environmental impact immediately. The model can be guidelines for environmental sustainable management by the prediction. In this study using Soil and Water Assessment Tools (SWAT) version 2012 predict organic pollutants and heavy metals transportation. The calibration of model presented simulated values and measured values almost the same including average monthly flow rates, and water quality data. However, the model verification for long term has to update to data at that time such as land use changing, soil properties changing, and precise weather prediction.

Keywords- Soil and Water Assessment Tools (SWAT), Organic pollutants, Heavy metals, Chao Phraya basin.

I. INTRODUCTION

For model development to evaluate contaminants transportation is significantly for assess environmental impact in future. If the model is working and precisely simulated, it can be well-timed environmental impact resolution. In this study, the SWAT model located in the ArcGIS will be used to simulate the organic pollutants and heavy metals movement in the lower Chao Phraya River, Thailand. The SWAT model has been widely used by several researchers in the world for "Simulation of Runoff, and water quality" [1]-[6]. However, it is rarely used to predict the organic pollutants and heavy metals transport in the river. As a result, the application of the SWAT for the prediction of organic pollutants and heavy metals distribution would be very useful for the land use and environmental management to control the quality of water in the Chao Phraya River.
For model development to suitable working have to collect primary data relate to study area following Digital Elevation Model, Land use, soil data, weather data, and water quality data. When data are enough, the model can run to get the results to calibrate and verify with observations for reliability. To verify model, water sampling at the field are required at the inlet of the lower Chao Phraya River include Pasak River, Upper Chao Phraya River, and Noi River and outlet of the lower Chao Phraya River is the estuary of Chao Phraya River. The corrected model is using for simulate water quality to check with raw water quality standard of water supply.

II. DETAILS EXPERIMENTAL

In this study, the following tasks have been carried out:

2.1 Model Development

The necessary data for model development that are required from the related agency in Thailand include rain fall intensity at the nearby station, existing land use, soil types, water flow rate variation, and etc. The application of SWAT will be performed by adding all available data to the SWAT database. Then, the simulation results by SWAT will be expressed.
SWAT is the acronym for Soil and Water Assessment Tool, a river basin or watered, scale model developed by Dr. Jeff Arnold for the USDA Agriculture Research Service (ARS). The SWAT model is a mainly tool used to predict the long-term impacts of management measures on water, sediment and agricultural chemical yield in large complex watersheds with varying soils, land use and management conditions.

- **Pesticides in the water**

Pesticide in a well-mixed water body is increased through addition of mass in inflow, resuspension and diffusion from the sediment layer. The amount of pesticide in a well-mixed water body is reduced through removal in outflow, degradation, volatilization, settling and diffusion into the underlying sediment in [7].
The amount of pesticide that is removed from the water via degradation is:

$$pst_{deg,wtr} = k_{p,aq} \cdot pst_{lkwtr} \quad (1)$$

Where $pst_{deg,wtr}$ is the amount of pesticide removed from the water via degradation (mg pst), $k_{p,aq}$ is the rate constant for degradation or removal of pesticide in the water (1/day), and pst_{lkwtr} is the amount of pesticide in the water at beginning of the day (mg pst). The rate constant is related to the aqueous half – life:

$$k_{p,aq} = \frac{0.693}{t_{1/2,aq}} \quad (2)$$

Where $t_{1/2,aq}$ is the aqueous half-life for the pesticide (day).

Pesticide in the dissolved phase is available for volatilization. The amount of pesticide removed from the water via volatilization:

$$pst_{vol,wrt} = v_v \cdot SA \frac{F_d \cdot pst_{lwtr}}{V} \quad (3)$$

Where $pst_{vol,wrt}$ is the amount of pesticide removed via volatilization (mg pst), v_v is the volatilization mass-transfer coefficient (m/day), SA is the surface area of the water body (m^2), F_d is the fraction of total pesticide in the dissolved phase, and V is the volume of water in the water body (m^3 H_2O).

In this type system the transfer coefficient or velocity is:

$$v_v = K_l \cdot \frac{H_e}{H_e + R \cdot T_k \cdot (K_l/K_g)} \quad (4)$$

Where K_l is the mass-transfer velocity in the liquid laminar layer (m/day), K_g is the mass-transfer velocity in the gaseous laminar layer (m/day), H_e is Henry's constant (atm m^3 $mole^{-1}$), R is the universal gas constant (8.206×10^{-5} atm m^3 (K mole)$^{-1}$), and T_k is the temperature (K).

Alternatively, the transfer coefficients can be estimated with the equations:

$$K_l = K_{l,o_2} \cdot \left(\frac{32}{MW}\right)^{0.25} \quad (5)$$

$$K_g = 168 \cdot \mu_w \cdot \left(\frac{18}{MW}\right)^{0.25} \quad (6)$$

Where K_{l,o_2} is the oxy gen transfer coefficient (m/day), MW is the molecular weight of the compound, and μ_w is the wind speed (m/s).

The amount of pesticide that is removed from the water via settling is:

$$pst_{stl,wtr} = v_s \cdot SA \cdot \frac{F_p \cdot pst_{lkwtr}}{V} \quad (7)$$

Where $pst_{stl,wtr}$ is is the amount of pesticide removed from the water due to settling (mg pst), v_s is the settling velocity (m/day), and F_p is the fraction of toatal pesticide in the particulate phase.

The amount of pesticide removed from the water body in outflow is:

$$pst_{sol,o} = Q \cdot \frac{F_d \cdot pst_{lkwtr}}{V} \quad (8)$$

$$pst_{sord,o} = Q \cdot \frac{F_p \cdot pst_{lkwtr}}{V} \quad (9)$$

Where $pst_{sol,o}$ is the amount of dissolved pesticide removed via outflow (mg pst), $pst_{sord,o}$ is the amount of particulate pesticide removed via outflow (mg pst), and Q is the rate of outflow from the water body (m^3H_2O/day).

- **Heavy metals routing**

Heavy metals are pollutants that are increasingly under scrutiny. Most heavy metals can exist in a number of different valence states it is in. The complexity of the processes affecting heavy metal solubility makes modelling these processes directly unrealistic. SWAT allows heavy metal loadings to be added to the stream network in point source loading inputs. SWAT currently routes the heavy metals through the channel network. Simple mass balance equations are used to determine the movement of heavy metals through the river network in [8].

$$\frac{dM}{dt} = M_I - M_o + G - C \quad (10)$$

Where $\frac{dM}{dt}$ is the rate of change of the heavy metal, M_I is inflow heavy metal, M_o is outflow heavy metal, G is the rate of generation, and C is the rate of consumption.

2.2 Field Survey and Data Collection

Observation data from the water samples such as specific Organochlorine Pesticides (OCPs) and heavy metals. The inlet observer locations were Wat Phananchoeng (Pasak River), Wat Nang Gui (Upper Chao Phraya River), and Sanam Chai fishing resort (Noi River). The outlet observer location was Phra Chulachomklao Fort (Chao Phraya River). Using SensION + MM150 Portable pH/ORP/EC Kit HACH to analyse water sample in the field investigation for pH, TDS, Temperature, and EC immediately.

2.3 Data Preparation

- **Digital Elevation Model (DEM)**

Digital Elevation Model (DEM) is a digital cartographic/geographic dataset of elevations in xyz coordinates. The terrain elevations for ground positions are sampled at regularly spaced horizontal intervals. The SRTM 90 m DEM's had a resolution of 90m at the equator, and is provided in mosaiced 5 degree x 5 degree tiles.

- **Land Use and Soil**

Land use data is individual data for each study area. In this study area, come from Land Development Department. Soil data using Food and Agriculture Organization of the United Nations (FAO) soil map.

- **Weather data**

The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) was completed over the 36-year period of 1979 through 2014.

- **Water qualities and quantity.**

Water qualities come from Pollution Control Department of Thailand and Water quantity come from Royal Irrigation Department of Thailand.

A. Model Modification

- **Delineation Watershed**

DEM GeoTiff file to grid file type and projected to WGS 1984 UTM 47N by using Arc Toolbox. Then input DEM in Automatic Watershed Delineation. Next step, build the mask on the study area to create steams and outlets in the study area. Selected estuary of Chao Phraya River to be whole watershed outlet and create the watershed.

- **Land Use**

Land use reclassify land use data were shown percentage of area for each land use in Fig. 1.

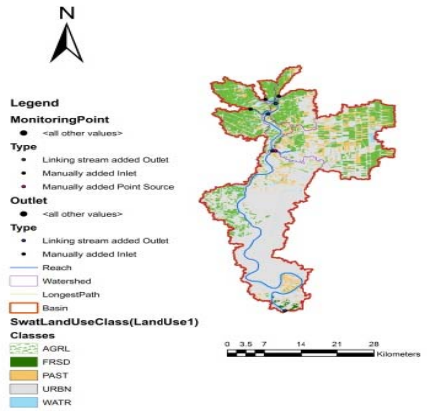


Fig. 1 Land Use of the Lower Chao Phraya basin.

Agricultural Land, AGRL is 26,613.5493 hectare (25.91% weight by Area), Forest-Deciduous, FRSD is 336.1947 hectare (0.33% weight by Area), Pasture, PAST is 9,406.5724 hectare (9.16% weight by Area), Residential, URBN is 60,471.1912 hectare (58.87% weight by Area), Water, WATR is 5,883.8368 hectare (5.73% weight by Area).

- **Soils**

Soils data reclassify were shown percentage of area for each soil in Fig. 2.

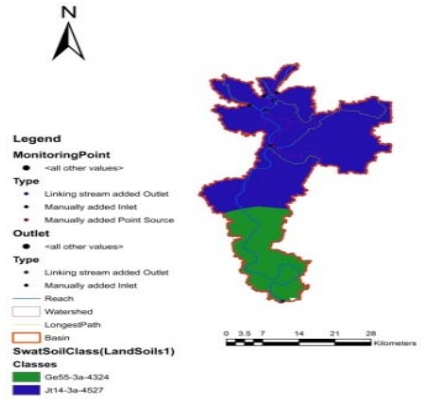


Fig. 2 Soils of the Lower Chao Phraya basin.

Ge55-3a-4324 is 25,610.9841 hectare (24.93% weight by Area), Jt14-3a-4527 is 77,100.3603 hectare (75.07 % weight by Area).

- **Input Modification**

The Edit SWAT Input menu allows for edit the SWAT model databases and the watershed database files containing the current inputs for the SWAT model. This option allows to enter the following data: average daily water loading (flow) [m^3], sediment loading [tons], organic nitrogen [kg], organic phosphorus [kg], nitrate (NO_3) [kg], ammonia (NH_3) [kg], nitrite (NO_2) [kg], mineral (soluble) phosphorus loading [kg], CBOD loading [kg], dissolved oxygen loading [kg], chlorophyll a loading [kg], soluble pesticide loading [kg], sorbed pesticide [kg], persistent bacteria, less persistent bacteria (both in [# bacteria/100 ml]), conservative metal 1 [kg], conservative metal 2, conservative metal 3 [kg], as required by the SWAT model. This data represents average daily loadings input to the stream network every day of the simulation.

There are 4 types of the input data include constant, annual records, monthly records, and daily records. For daily constant input allows directly edited in the SWAT model and annual records, monthly records, and daily records have to edited in text file or dbf file before add to model. This study selected monthly records type from January 2010 until December 2013. The main target of the research is soluble pesticide transportation and heavy metals. For pesticide evaluate have to pesticide database adjustment including different half-life ($t_{1/2}$) in SWAT database before simulation model have to adjust subbasin water quality data (swq table) to match with the considered pesticide. In this case soluble pesticide input is p,p'-DDT, half-life ($t_{1/2}$) of p,p'-DDT is 120 days. The input of heavy metals can be input directly, conservation metal 1 is Chromium (Cr) and conservation metal 2 is Lead (Pb) in 3 inlet points.

The data input points including inlet 1 is the inlet from Pasak River, Inlet 2 is the inlet from Upper Chao Phraya River, and Inlet 4 is the inlet from Noi River.

III. RESULTS AND DISCUSSION

For model developments including two parts were model calibration and model verification.

3.1 Model Calibration

- **Flow Calibration**

For the calibration flow rate of SWAT2012 model the simulation result quit similar tent with the observation data by compare from January 2012 to December 2013 shown in Fig. 3. For this case the coefficient of determination, R^2 is 0.96 that the result is less error.

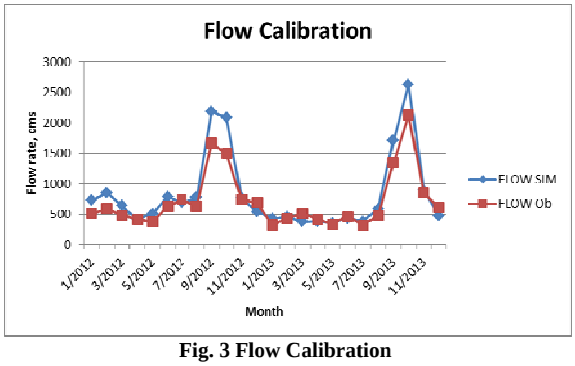


Fig. 3 Flow Calibration

Where FLOW SIM is the simulation flow rate (m^3/s), FLOW Ob is the observation flow rate (m^3/s)

- **Heavy Metal Calibration**

Cadmium, the coefficient of determination, R^2 is 0.90 that the result is less error the result shown in Fig. 4. Lead, the coefficient of determination, R^2 is 0.77 (value is lowest) because from Febuary to August

2012 the concentration of Lead, Pb was different tent when compare simulation and observation value shown Fig. 5.

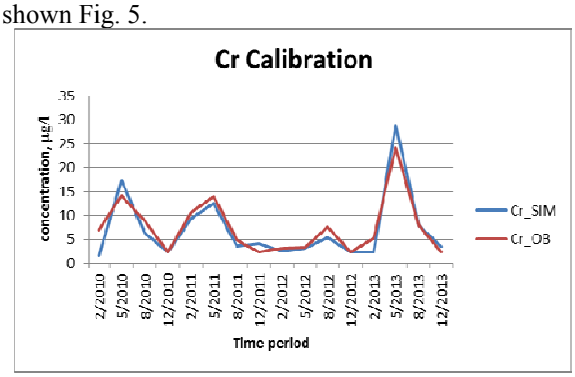


Fig. 4 Cadmium Calibrations

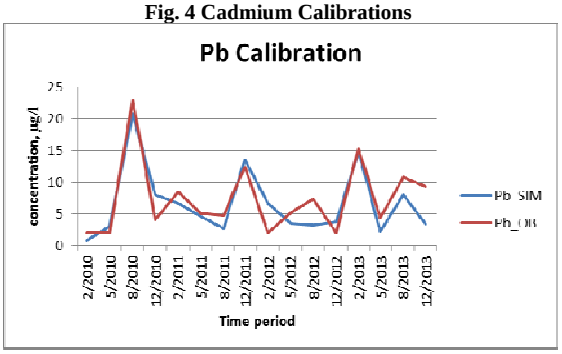


Fig. 5 Lead Calibrations

- **Pesticide Analysis**

For soluble p,p'-DDT result for input p,p'-DDT concentration at 0.012 ug/l in December 2010 into 0.409 mg/d p,p'-DDT loading. From simulated result showed loss of pesticide from water by reaction during time step is 0.002853 mg and Loss of pesticide from water by volatilization during time step is 0.001501 mg. and p,p'-DDT transfer result had decreasing tend shown in Fig. 7 and legend definition shown in Table 1.

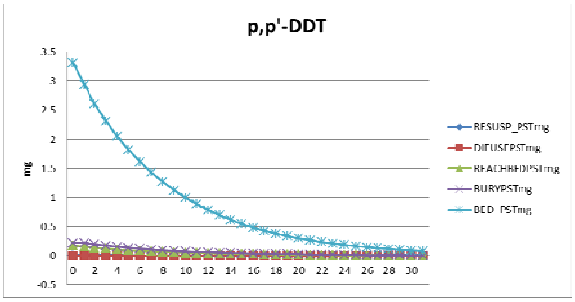


Fig. 7 p,p'-DDT Transfer

TABLE I PESTICIDE ANALYSIS DEFINITION

NAME	DEFINITION
SETTLPST	Transfer of pesticide from water to river bed sediment by settling during time step (mg active ingredient).
RESUSP_PST	Transfer of pesticide from river bed sediment to water by resuspension during time step (mg active ingredient).
DIFFUSEPST	Transfer of pesticide from water to river bed sediment by diffusion during time step (mg active ingredient).
REACBEDPST	Loss of pesticide from river bed sediment by reaction during time step (mg active ingredient).
BURYPST	Loss of pesticide from river bed sediment by burial during time step (mg active ingredient).
BED_PST	Pesticide in river bed sediment during time step (mg active ingredient).

3.2 Model Verification

Input observation water quality of inlet. The simulation results of water quality at the estuary of Chao Phraya River including Organochlorine Pesticides are not detected, Ammonia Nitrogen (NH_3) 0.87 mg/l, Nitrate (NO_3-N) 0.35 mg/l, Nitrate (NO_2-N) 0.30 mg/l, Chromium (Cr) 0.0012 mg/l, and Lead (Pb) 0.0008 mg/l. The estuary of Chao Phraya River field investigates including pH 7.32, Electro Conductivity 673 µs/cm, Oxidation-Reduction Potential 220 Mv, and water temperature 31.3 °C. Organochlorine Pesticides are not detected, Ammonia Nitrogen (NH_3) 1.21 mg/l, Nitrate (NO_3-N) 0.50 mg/l, Nitrate (NO_2-N) 0.20 mg/l, Chromium (Cr) 0.0015 mg/l, and Lead (Pb) 0.001 mg/l. The simulation results close to observation results when compare in the water quality term. When compare observation with simulation the results have a few percentage difference shown in Table 2.

TABLE 2 The comparison of data

Parameter	Observation (mg/l)	Simulation (mg/l)	percentage difference
Cadmium	0.0015	0.0012	24 %
Lead	0.001	0.0008	22 %

CONCLUSIONS

In this study, water quality management model was developed for water pollution control in a river. The SWAT2012 programming optimization was used in SWAT model formulation. The decision variables in the management model were the controllable heavy metals and OCPs loads from various sources along the river. In applying the developed model to the Lower Chao Phraya River, the results clearly shown effectiveness of the SWAT2012 model which can help provide useful information for decision makers in establishing their pollution control strategies effectively. The SWAT2012 can be adjusting to predict the water quality and water quantity to preparation the way to solve future problem by adjust the inlet discharges or point source data. By the way

SWAT2012 should be update some data including Land use, Soil data, weather data to be the precisely results.

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