Interaction Fugacity Model for Water, Sediment and Seagrass

Faridahanim Ahmad, Shamila Azman, Mohd Ismid Mohd Said, Nor Hazren Abdul Hamid, Hasnida Harun, Mariah Awang, Mohamad Ashraf Abdul Rahman

Abstract: Fugacity concept is convenient in environmental chemical equilibrium. Mathematical model for simulation of chemical movement in the estuary consists of 3 compartments which are water, sediment, and seagrass. The influence factors at site location such as area, depth, volume, mass of water, mass of sediment, mass of seagrass, and current water flow were identified. The current water flow at Pulai River Estuary was measured in order to identify the allowable distance from mouth of Pulai River to Pulaiseagrass bed. The average wind speed can be found from World Weather and Climate information, 2015. The estimation method is practically used for getting the approximate estimation of concentration in each medium. The ratio of the concentration in each medium is called 'concentration factor'. The ratio between seawater and sediment is 1: 1.439 x 10^{-3}; ratio between sediment and seagrass is1: 4.25 x 10^{-9}; and the ratio between seawater and seagrass is 1: 6.11x 10^{-12} C_3. Thus, quantitative water, sediment and seagrass fugacity/ aquivalence mass balance model was developed for Pulai River Estuary is relevant.

Keywords: Estuary, Fugacity, Modeling, Seagrass.

I. INTRODUCTION

Aquantitative water, sediment and seagrass fugacity/ aquivalence mass balance model was developed for Pulai River Estuary. This model was based on fugacity concept. The concept was studied by [1,2,3]. In this study, the quantitative water, sediment and seagrass fugacity/ aquivalance balance model followed studies by [4]. The fugacity concept is convenient in environmental chemical equilibrium.

Revised Manuscript Received on May 22, 2019.

Faridahanim Ahmad, Department of Civil Engineering Technology9 Faculty of Engineering Technology, UniversitiTunHussienOnn Malaysia, 84600, Pagoh, Johor

Shamila Azman, School of Civil Engineering, Faculty of Engineering, UniversitiTeknologi Malaysia, 81310, Skudai, Johor

Mohd Ismid Mohd Said, School of Civil Engineering, Faculty of Engineering, UniversitiTeknologi Malaysia, 81310, Skudai, Johor

Nor Hazren Abdul Hamid, Department of Civil Engineering Technology, Faculty of Engineering Technology, UniversitiTunHussienOnn Malaysia, 84600, Pagoh, Johor

Hasnida Harun, Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti TunHussien Onn Malaysia, 84600, Pagoh, Johor

Mariah Awang, Department of Civil Engineering Technology, Faculty of Engineering Technology, UniversitiTunHussienOnn Malaysia, 84600, Pagoh, Johor

Mohamad Ashraf Abdul Rahman, Department of Civil Engineering Technology, Faculty of Engineering Technology, UniversitiTunHussienOnn Malaysia, 84600, Pagoh, Johor

The equations in fugacity implement a relative simple. The dominant environment factors were selected such as water, sediment, plant. Thus this concept has been widely used in chemical process calculation. To assess the validity of the model, the results were compared with observed contaminant concentrations in water and sediment.

Although the simulated model results were an approximation due to uncertainties and gaps in data such as different current at each water depth and air circulation. It is hoped that the model will be useful tool for illustrating the behaviour of chemical in estuary, quantifying the effect of water, sediment and seagrass exchange processes, distinguishing between processes and factors that are important, and determining which aspects of the parameter are needed to further investigation.

II. CASE STUDY LOCATION

Mathematical model for the simulation of the chemical movement in the estuary consists of 3 compartments which are water, sediment, and seagrass as shown in Figure 1.Two areas were selected in this study which is the upstream of Pulai River and seagrass bed ofPulai River Estuary. Figure 1 shows the aerial map of study location. Pulai River has several tributaries with associated mangrove, intertidal mudflats and inland freshwater that represent lowland tropical river basin. Pulai River flows from Mount Pulai up to the Johor Straits in which the seagrass bed of Pulai River Estuary is located.

The seagrass bed of Pulai River Estuary is the largest in Malaysia with an approximate area of 3.15 km² [5]. Besides Johor Straits, Malacca Straits and Singapore Straits also contributes to water that flows into the seagrass bed at Pulai River Estuary.Seagrass bed of Pulai River Estuary is located between two powerful regional hubs of Johor and Singapore. Hence, its location is geographically strategic on the world's busiest shipping routes eastbound and westbound [6].

Furthermore, it is also surrounded by many projects such as Port of TanjungPelepas (PTP), Tanjung Bin Power Plant, Asia Petroleum Hub and development area from Tuas, Singapore. The distance between PTP to seagrass bed is 4 kilometers. The distance between Asia Petroleum Hub to the seagrass bed is 5.5 kilometres. The distance between Tuas, Singapore to the seagrass bed is 3 kilometers. Thus the seagrass bed is surrounded with pollution area.

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication*

Currently development at Iskandar Malaysia is swift with various undergoing projects. The latest development is Forest City, a mega-project with an artificial island of nearly 2000 hectares or half the size of Putrajaya which is located in the Johor Straits [7]. The huge island was reported to be a collaboration between renowned China developer Country Garden Holdings (based in Guangdong) and Johor state-owned People Johor Infrastructure Group [8].

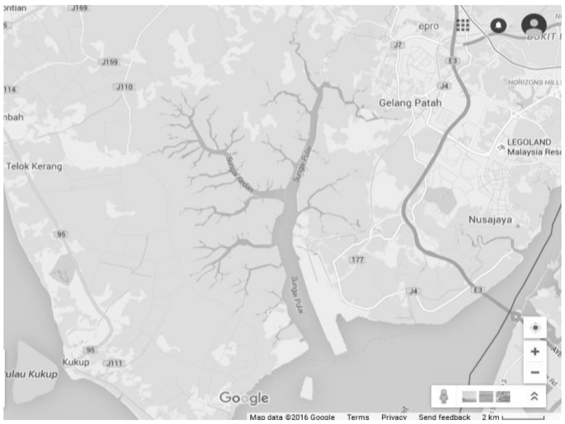

Fig. 1 Location of study area

In 2015, construction and reclamation for Forest City to be built on a man-made island in the Johor Strait was approved by Malaysia Department of Environment as long as they ensure that all compliance monitoring in terms of air, noise, water quality and sediment are robustly implemented and carried out. In order to comply with Malaysia Department of Environment standards, the total size of Forest City was slightly reduced from 1,623 hectares to 1,386 hectares and divided into four reclaimed islands instead of one huge island as in Figure 2. Even though Forest City is divided into four reclaimed island, the development will still effect to seawater hydrodynamic. Apart from that, nearby the seagrass bed is also the expansion of 1,410 hectares reclamation project for an oil and gas hub.

Fig. 2 Reclamation area of Forest City that overlaps with Pulai River Estuary seagrass bed. New Forest City with four islands after approval from Malaysia Department of Environment [9]

III. METHODOLOGY

Mathematical model for the simulation of the chemical movement in the estuary consists of three compartments which are water, sediment, and seagrass as shown in Figure 3.

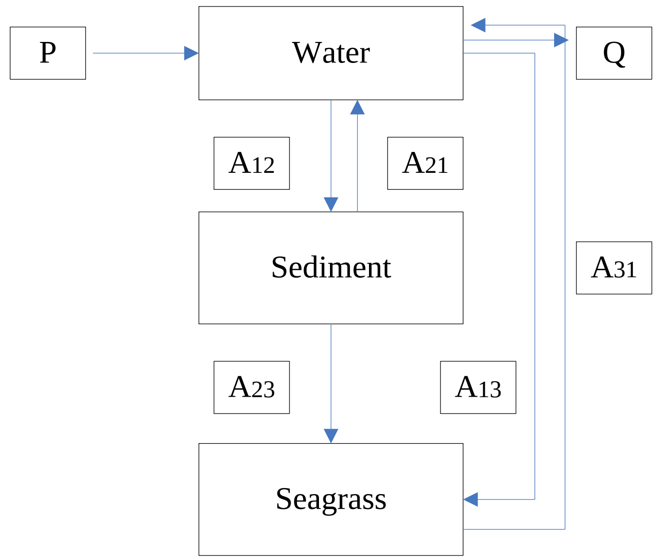

Fig. 3 Model of process interaction between water, sediment and seagrass

The parameters of the chemical movement:
P: Input of the chemical
Q: Output of the chemical
A_{ij}: Flow of the chemical from compartment i to j
A_{12}: Flow of the chemical from water to sediment
A_{23}: Flow of the chemical from sediment to seagrass
A_{21}: Flow of the chemical from sediment to water
A_{13}: Flow of the chemical from water to seagrass
A_{31}: Flow of the chemical from seagrass to water

The model can be generally expressed by equation 1:

$$dM_i C_i = -\Sigma Aij + \Sigma Aji + P - Q \qquad (1)$$

$(i, j = 1,2,3)$

where,
M_i : Mass of compartment i
C_i : Concentration of the chemical in compartment i

Simultaneous differential equation depending on the assumed model is as follows equation 2, 3 and 4:

$$dM_1 C_1 = -A_{12} + A_{21} - A_{13} + A_{31} + P - Q \qquad (2)$$

$$dM_2 C_2 / dt = -A_{12} - A_{21} - A_{23} \qquad (3)$$

$$dM_3 C_3 / dt = -A_{23} + A_{13} - A_{31} \qquad (4)$$

The influence factor at site location such as area, depth, volume, mass of water, mass of sediment, mass of seagrass, and current water flow were identified. The current water flow at Pulai River Estuary was measured in order to identify the allowable distance at study area from mouth of Pulai River to Pulaiseagrass bed.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The average wind speed over a year can be obtained from [10].Figure 4 is the average of monthly wind speed in meters per second. Other influences factors such as area, depth and volume of water and sediment were calculated as shown in Table 1, the calculations for mass of water, sediment and seagrassis shown in a Table 2.

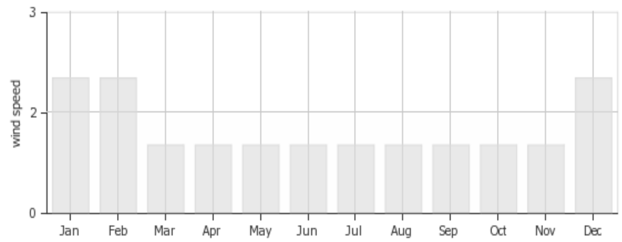

Fig. 4 Average monthly wind speed

Table. 1 Area, depth and volume of water and sediment

Specimen	Water	Sediment
Area (m^2)	5700 x 2400	5700 x 2400
Depth (m)	3	0.03 [4]
Volume (m^3)	4.1 x 10^7	4.1 x 10^5

Table. 2 Mass of water, sediment and seagrass

Specimen	Mass	
Water	Properties	V_1 = 4.1 x 10^7 m^3 ; Density = 2 kg/L [4]
	Density in kg/m^3	= 2 kg/L x 1000 L/m^3
		= 2000 kg/m^3
	Mass, M_1	= 4.1 x 10 m^3 x 2000 kg/m^3
		= 8.2 x 1010 kg
Sediment	Properties	V_2 = 4.1 x 10^5 m^3 ; Density of sediment = 2.64 kg/L [4]
	Density in kg/m^3	= 2.64 kg/L x 1000 L/m^3
		= 2640 kg/m^3
	Mass, M_2	= 4.1 x 10^5 m^3 x 2640 kg/m^3
		= 1.08 x 109 kg
Seagrass	Average species of 1 meter x 1 meter transect	= 3 *Enhalusacoroides* + 25 *Halophilaovalis* +20 *Halophila minor*
		= (3 x 8.3) + (25 x 5) + (20 x 5)
		= 250 g
	Seagrass cover area	= 1610 m x 376 m
	Percentage of average seagrass cover	= *67%*
	Mass, M_3	= 1610 m x 376 m x 67/100 x 1kg/1000 g

= 101398 kg

A_{12} = C_1 µg/kg× 8.2 x 10^{10} kg/day x 0.915

0.915 is sediment porosity [4]

= 7.503 x 10^{10} C_1 µg/day

A_{21} = C_2 µg/kg× 1.08 x 10^9 kg/day x 5 x 10^{-6}

5 x 10^{-6} is volume fraction of water [4]

= 5400 C_2 µg/day

A_{23} = C_2 µg/kg×1.08 x 10^9 kg/day x 0.1

0.1 is plant porosity [11]

=1.08 x $10^8 C_2$ µg/day

A_{13} = C_1 µg/kg× 8.2 x 10^{10} kg/day x 0.1

= 8.2 x 10^9 C_1 µg/day

A_{31} = C_3 µg/kg× 101 398 kg/day x 5 x 10^{-6}

= 0.51 C_3 µg/day

Set the initial input and output as 0, and then the simultaneous differential equation becomes:

$dM_1C_1/dt = -7.5 \times 10^{10} C_1 + 5400 C_2 - 8.2 \times 10^9 C_1 + 0.51 C_3$

$dM_2C_2/dt = 7.503 \times 10^{10} C_1 - 5400 C_2 - 1.08 \times 10^8 C_2$

$dM_3C_3/dt = 1.08 \times 10^8 C_2 + 8.2 \times 10^9 C_1 - 0.51 C_3$

Substitute M_1, M_2 and M_3 :

$(8.2\times 10^{10})\, dC_1/dt = -7.5\times10^{10} C_1 + 5400 C_2 - 8.2 \times10^9 C_1 + 0.51 C_3$

$(1.08 \times10^9)\, dC_2/dt = 7.503 \times10^{10} C_1 - 5400 C_2 - 1.08 \times 10^8 C_2$

$(101\,398)\, dC_3/dt = 1.08 \times 10^8 C_2 + 8.2 \times 10^9 C_1 - 0.51 C_3$

Then we should check that the unit of the both side is in µg/day.The simultaneous differential equation can be expressed as:

$dC_1/dt = -1.015 C_1 + 6.58 \times 10^{-8} C_2 + 6.21 \times 10^{-12} C_3$

$dC_2/dt = 69.47 C_1 - 0.1 C_2$

$dC_3/dt = 80869 C_1 - 1065 C_2 - 5.02 \times 10^{-6} C_3$

Discretize the left side of each as in equation 5, 6 and 7:

(C1t+Δt – C1t)/Δt = -1.015 C1t + 6.58 x 10-8 C2t + 6.21 x 10-12 C3t (5)

(C2t+Δt – C2t)/Δt = 69.47 C1t – 0.1 C2t (6)

(C3t+Δt – C3t)/Δt = 80 869 C1t -1065 C2t – 5.02 x 10-6 C3t (7)

where,

$C_i^{t+\Delta t}$: concentration of compartment i at time t+Δt

C_i^t : concentration of compartment i at time t

Δt : discretization of time

IV. RESULT AND DISCUSSION

The equation from 5 to 7 meaning that the concentration of other compartments can be determined by knowing by only one component. This estimation method is practically used for getting approximate estimate the concentration of each medium. The ratio of the concentration of each medium is called ‘concentration factor’.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

In case of equilibrium the initial condition of the concentration of each compartment is 0.

$0 = -1.015\ C_1 + 6.58 \times 10^{-8}\ C_2 + 6.21 \times 10^{-12}\ C_3$

$0 = 69.47\ C_1 - 0.1\ C_2$

$0 = 80869\ C_1 - 1065\ C_2 - 5.02 \times 10^{-6}\ C_3$

At equilibrium condition, the concentration of each compartment is estimated. Hence the relation between concentrations of each compartment is:

$C_1 = 1.439 \times 10^{-3}\ C_2$

$C_2 = 4.25 \times 10^{-9}\ C_3$

$C_3 = 6.11 \times 10^{-12}\ C_3$

This means the ratio between seawater and sediment is 1: 1.439 x 10^{-3}; ratio between sediment and seagrass is1 : 4.25 x 10^{-9}; and the ratio between seawater and seagrass is 1 : 6.11x 10^{-12} C_3. For example the input of Pb concentration into estuary is 100 µg/L, so Pb concentration in water is 99.8 µg/L, whereas Pb concentration in sediment is 0.14 µg/kg and Pb concentration in seagrass is 6.11 x 10^{-10} µg/kg. The estimation rates of metals concentration in water, sediment and seagrasses correspond to loading as illustrated in Figure 5 to Figure 8.

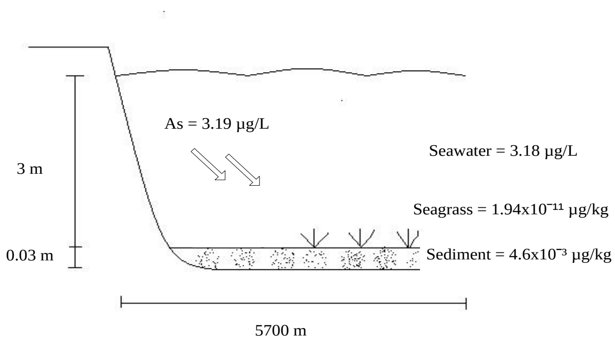

Fig. 5 Estimation rates for As concentration in water, sediment and seagrasses corresponding to loading in 1 day

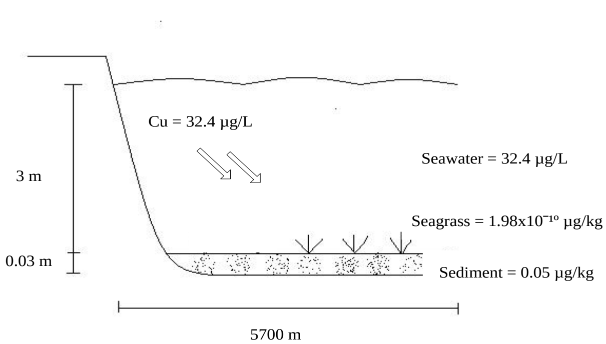

Fig. 6 Estimation rates for Cu concentration in water, sediment and seagrasses corresponding to loading in 1 day

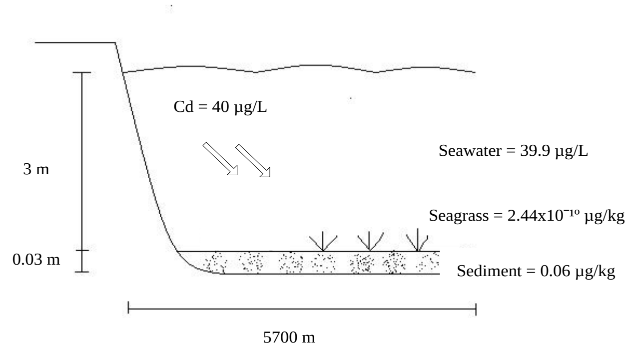

Fig. 7 Estimation rates for Cd concentration in water, sediment and seagrasses corresponding to loading in 1 day

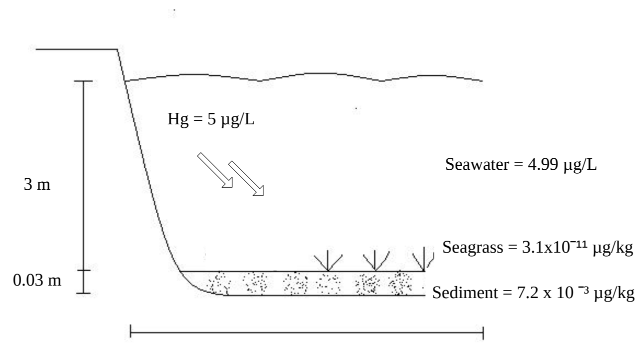

Fig. 8 Estimation rates for Hg concentration in water, sediment and seagrasses corresponding to loading in 1 day

V. ACKNOWLEDGEMENTS

The authors wish to thank to MyBrain15 from Ministry of Higher Education (MOHE) for scholarship and Universiti Teknologi Malaysia for grant financial support (UTM RUG Vot 03J65). The authors also wish to thank to UniversitiTunHussienOnn Malaysia (Tier 1, Grant Vot: H228) for financial support in publishing paper.

REFERENCES

1. D. Mackay, and M. Diamond, "Application of the QWASI (Quantitative Water Air Sediment Interaction) Fugacity Model to the Dynamics of Organic and Inorganic Chemicals in Lakes,"*Chemosphere*, vol. 18 (7 - 8), pp. 1343 – 1365, 1989.
2. D. Mackay,L. Hughes,D. E. Powell, and J. Kim,"An Updated Quantitative Water Air Sediment Interaction (QWASI) Model for Evaluating Chemical Fate and Input Parameter Sensitivities in Aquatic Systems: Application to D5 (Decamethylcyclopentasiloxane) and PCB-180 in Two lakes,"*Chemosphere*, vol. 111, pp. 359 – 365, 2014.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

3. D. Mackay, M. Joy, and S. Paterson, "A Quantitative Water, Air, Sediment Interaction (QWASI) Fugacity Model for Describing the Fate of Chemicals in Lakes,"*Chemosphere*, vol. 12 (7 - 8), pp. 981 – 997,1983.
4. H. Ling, M. Diamond, and D. Mackay, "Application of the QWASI Fugacity/Aquivalence Model to Assessing Sources and Fate of Contaminants in Hamilton Harbour," *J of Great Lakes Res.*, vol. 19 (3), pp. 582 – 602, 1993.
5. N. Sabanayagam,"Food for Marine Life Under Treat,"*New Straits Times,* pp. 13,Jan. 2008.
A. Rizzo, and J. Glasson,"Iskandar Malaysia,"*Cities,*Vol. 29, pp. 417 – 427, 2012.
6. M. M. Arsad, "KerajaanNegeriNafiAmbikBalik Tanah PTP,"Utusan. Retrieved February 11, 2015, from http: //ww1. utusan. com. my/ utusan/ Ekonomi/ 20140711/ ek_05/ Kerajaan – negeri – naïf – ambil – balik – tanah – PTP, Jul. 2014.
7. N. Aw,"The Case of Forest City and the Johor Sultan,"*Malaysia Kini*.http: // www. malaysiakini.com /news /268649, Jul. 2014.
8. M. Lee,"Controversial Johor Strait land reclamation project Forest City gets the go-ahead,"*The Straits Times*.http: //www. straitstimes. com/ business/ controversial – johor – strait – land – reclamation – project – forest – city -gets-the-go-ahead, Jan. 2015.
9. World Weather and Climate information. "Average Weather in Johor Bahru Malaysia,"http://www. Weather – and – climate. Com/average – monthly – Rainfall-Temperature - Sunshine, johor - bahru, Malaysia, 2015.
10. T. S. Pathak, J-H. Yun,J. Lee, and K-J. Paeng, "Effect of Calcium Ion (cross-linker) Concentration on Porosity, Surface Morphology and Thermal Behavior of Calcium Alginates Prepared From Algae (Undariapinnatifida)," *Carbohydr.polym.,*Vol. 8(3), pp. 633-639, 2010.