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Prediction of Phosphorus Migration in an Unconfined Aquifer with Visual MODFLOW in Landfill Area

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Abstract: In this study, movement of phosphorus pollution which is leachate to groundwater was investigated in Seri Petalling Landfill. Visual MODFLOW was used to predict subsurface and surface migration of pollution within 10 years. The results of sample analysing of phosphorus has shown its concentration in place of landflill was 2.38 mg/l since the National Water Quality Standard for Malaysia defined the maximum value of phosphorus in groundwater for Class IIA/IIB and III at 0.1 and 0.2 mg/l respectively. The prediction shows phosphorus migrated widely to further places such as river and it has adverse effect on environment, animal and human.

Key words: Groundwater Flow · MODFLOW · Phosphorus · Landfill · Pollution

INTRODUCTION

Groundwater contamination is one of the serious environmental problems that these days human face to it. Nutrient such as phosphate, phosphorus, nitrate, nitrite etc. which are recognized as pollution, have adverse effect in short time and/or long time on human body and ecosystem. In case of exceeding of phosphate and phosphorus, after long time they cause eutrophication which might be killed the fish and aquatic plants living in ponds, lakes, etc. and terrible odor and high turbidity due to elimination of aquatic plants in water body [1, 2]. These are significant problems created by phosphorus and phosphate. The Interim National Water Quality Standard for Malaysia defined the maximum value of phosphorus in groundwater for Class IIA/IIB and III in Malaysia at 0.1 and 0.2 mg/l respectively [3].

Simulation of groundwater flow and soluble contamination migration by computer is a way to cover the hiatus between field observations and characteristics water movement in porous media. Computer Software can simulate the spatial variability of groundwater flow from one point to other points also show interaction between surface and subsurface water. Along with such process it also possible to monitor and follow the contaminations which exist in groundwater or leachate from surface sources (such as nutrients) by lateral and/or vertical migration.

Visual MODFLOW is a Powerful software package using MODFLOW, MODFLOW SURFACT, MODPATH, MT3D/MT3DMS, MGO, Win PEST and SEAWAT-2000 to solve groundwater contamination and interaction between surface water and subsurface. This software consists of input, run and output sections. In first section characteristics of soil and groundwater and also boundary condition are assigned for software. Run section is designed to translate input section into the standard input to simulate. Output illustrates results of simulation included concentration of contamination, water level and so on [4]. These days Visual MODFLOW is used widely to model and simulate saturated groundwater flow. A lot of studies uses Visual MODFLOW software package and its features to predict and simulate conditions and behavior of groundwater and groundwater contamination in future [5-10].

In this paper, numerical modeling package, Visual MODFLOW (version 4.2.) was used to predict fate and transport of phosphorus in landfill of Seri Petaling, Selangor, Malaysia. Assessment on the concentration of phosphorus would be important to know amount of spreading of contamination in future. It might be helpful to control pollution in landfill.

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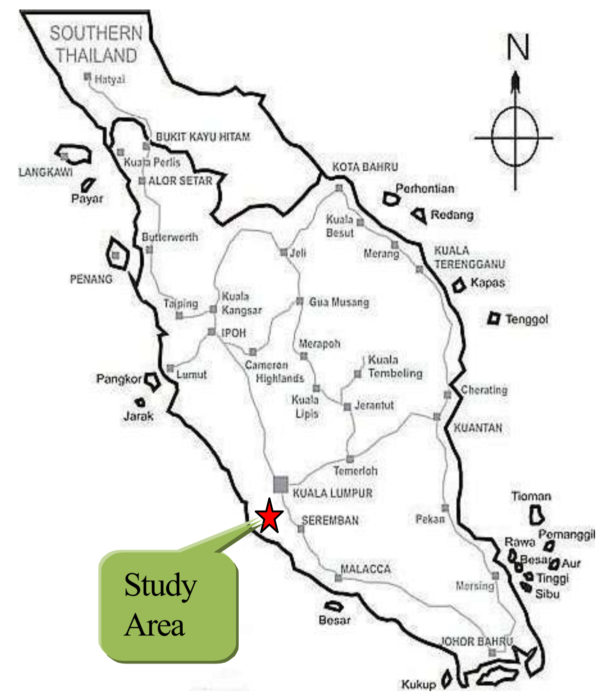

Fig. 1: Location of study area

MATERIALS AND METHODS

Study Site: Location of study area lies between 101° 41′ 18″ E, 101° 41′ 51″ E longitude and 3° 04′ 04″ N, 3° 04′ 20″ N latitude. The landscape is sloping with elevations that range from 25 m to 43 m above Mean Sea Level (MSL). The study area is located in tropical climate with annual average rainfall of 2900 millimeters. Soil and rock study indicates that the aquifer consists of Silty Clay. The layer is known as Kenny Hill formation [11, 12]. Figure 1 show the place of study area in southwest of Kuala Lumpur.

Groundwater Data: The parameters are inputted in software including Effective Porosity, Specific Yield, Specific Storage and Dispersivity of phosphorus in soil is extracted from literature. Some parameters assigned in the software for the simulation includes hydraulic conductivity, Porosity, thickness and type of soil were gathered between 1999 and 2001 in study area [13]. Amount of evapotranspiration (mm/y) and recharge (mm/y) are measured for study area was assigned to the model. The aquifer is considered as isotropic and heterogeneous.

Groundwater Flow Modeling: MODFLOW, a computer program, has been developed for U.S. Geological Survey in the form of modular three dimensional groundwater flow model. MODFLOW is able to simulate a wide range of flow in porous media with wide varieties of systems and standard including groundwater flow, transport of contamination (Harbaugh *et al*., 2005). MODFLOW solves for the distribution of hydraulic head within the model domain and, from these results, the velocity components of flow are calculated. The formula that is used to predict flow is:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_g\frac{\partial h}{\partial t} \quad (1)$$

Solute Transport Modeling: To simulate leachate of phosphorus into groundwater MT3DMS was used. MT3DMS simulate advection, dispersion and chemical reactions of contamination in groundwater. It uses the cell-by-cell data which is computed and outputted by MODFLOW to establish the results [14]. The formula that is used to predict flow is:

$$\frac{\partial\left(\omega C^k\right)}{\partial t}=\frac{\partial}{\partial x_i}\left(\omega D_{ij}\frac{\partial C^k}{\partial x_j}\right)-\frac{\partial}{\partial x_i}\left(\omega C^k\right)+q_s C_s^k+\sum R_n \quad (2)$$

Model Boundaries: The boundaries are assigned in software includes, i) Constant Head Boundary (CHB), ii) evapotranspiration boundary and iii) recharge boundary and iv) river boundary. The assigned values as recharge and evapotranspiration to whole cells of software are 288 mm/yr and 1550 mm/yr respectively. Figure 2 shows the river boundary which is assigned in software.

Model Calibration: Model results were used during the calibration phase in order to regress between the calculated data and those observed in the groundwater monitoring wells. Based on these results, Standards Error of the Estimation (SEE) was 0.058 mg/l. A root mean squared (RMS) value of 0.081 mg/l was achieved during calibration. The normalized RMS for the model was 3.992%.

RESULTS

Results of phosphorus measurement in study area have shown concentration of phosphorus in most part of study area is low while in landfill concentration of phosphorus in 2.38 mg/l. In comparison with Department of Environmental (2004) it shows high concentration.

We used the Visual MODFLOW (Waterloo Hydrogeologic, Inc.) and the model was run to steady-state for 1 and 10 years. As a matter of fact, phosphorus can not leach and move with groundwater in the short time because of high absorption capacity of the soil for

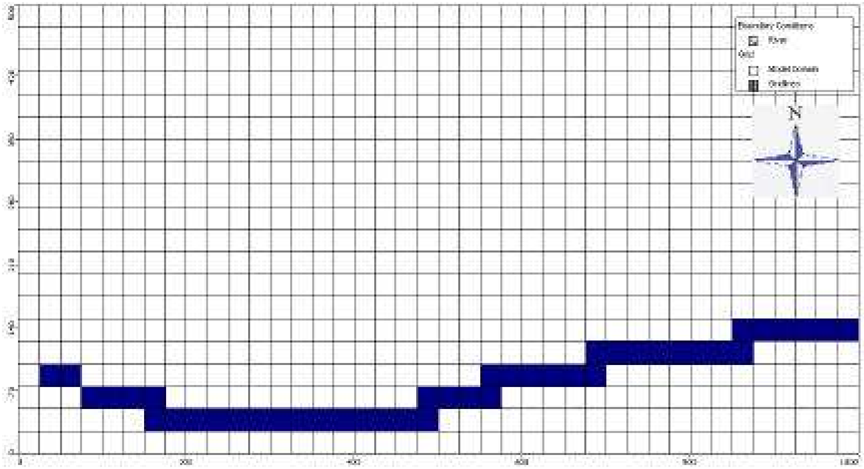

Fig. 2: Location of river boundary in study area

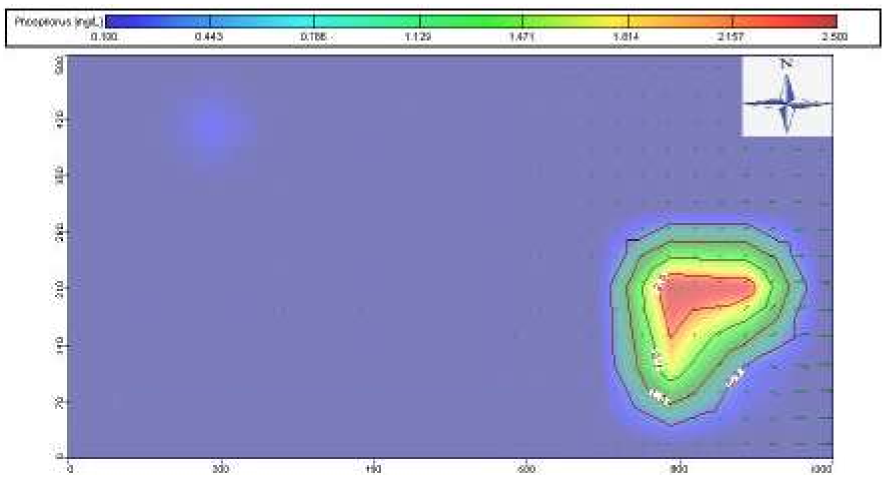

Fig. 3: Migration of contamination after 1 year

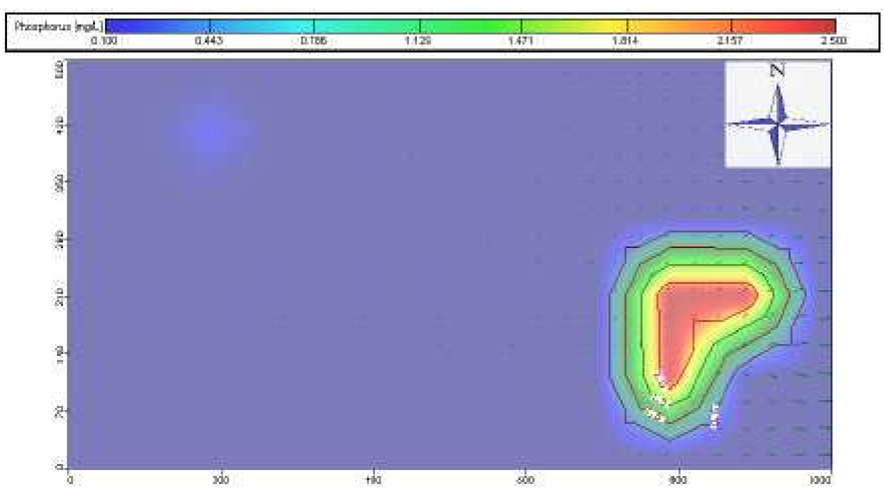

Fig. 4: Migration of contamination after 10 years

adsorption of phosphorus particles but mobility of phosphorus is resumed as the adsorption capacity of the soil is reached. This enables the groundwater carried phosphorus to bypass the soil particles which permits transportation of high concentration of phosphorus through the soil [15]. The results show phosphorus was not migrated widely along the groundwater flow (Figure 3) whereas the borehole number 3 is located exactly inside the landfill.

But after 10 years pollution plume is moving toward the south (into the river which is located in south of map) instead of movement along with groundwater. Regarding to Figure 4 pollution plume moving toward the river and infiltrate to surface water and transported to other place. It should be notified that X and Y axis are expressed in meter unit.

Due to place of landfill (landfill located in higher place and river is beside the landfill which is located in lower place), movement of groundwater in study area is effective by the river that is located in south of study area and movement of contamination toward the south (into the river) has indicated in figure 4.

DISCUSSION

The present research confirms that the unconfined aquifer is highly contaminated by phosphorus which is 2.38 mg/l when standard of the National Water Quality Standard for Malaysia is declared by Department of Environment (DOE) 0.1 mg/l for drinking water (Class IIA). 0.35 mg/L of phosphorus concentration in upper stream borehole was reported that showing there is no critical concentration existed before groundwater received by landfill and it is main source of contamination in region.

As a matter of fact, phosphorus cannot leach and move with groundwater in the short time because of high absorption capacity of the soil for adsorption of phosphorus particles [1] but mobility of phosphorus is resumed as the adsorption capacity of the soil is reached [15]. It should be noted that the periods of phosphorus migration prediction were selected different (1 and 10 years) to obtain the distinctive results and approving mobility of overloaded phosphorus within the longer time in study area. This enables the groundwater carried phosphorus to bypass the soil particles which permits transportation of high concentration of phosphorus through the soil [15].

Groundwater flow and solute transport modeling was effective to assess and predict of phosphorus concentration in subsurface zone in landfill zone. The prediction of phosphorus migration in groundwater might be a preliminary research and further study must be implemented to investigate migration of phosphorus better to prevent of spreading of phosphorus in study area and also preventing of entering in drinking water and portable water.

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