Assessment of Subsurface Condition of Peat Soil due to Brackish Groundwater Seepage

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Abstract. The purpose of this assessment is to assess the subsurface condition of peat soil due to brackish groundwater seepage along drainages using a numerical method. Visual MODFLOW is applied to conceptualize a condition in the study area and to produce outcomes related to the objectives of the study. The results of the simulation show there is only a small portion of high salt concentration along the drainage. The migration of salt concentration is mostly affected by the groundwater head and velocity vectors of the aquifer materials. Meanwhile, most of the other places in the study area receive a low salt concentration. Therefore, the impact of brackish groundwater on the environment is not significant since the salt concentration is low in most of the study area.

1. Introduction
Haze pollution is one of the most prominent disasters in Southeast Asia. This disaster happens almost every year in the fourth quarter of the year. This disaster is mostly due to open burning by plantation landowners in Indonesia to clear off their land. The purpose of land clearance is for farming and palm oil plantation. This has also become a trend in Sarawak.

Meanwhile, haze pollution in Kuala Baram, Miri occurs frequently during the dry season. Peat soil covers most of the plantation land in Kuala Baram. Peat soil is an unconsolidated superficial deposit with high non-crystalline colloid (humus) content in which forming the subsurface of wetland systems [1]. The dry peat from open burning activities burns easily during the dry season, and this creates smouldering peat [2]. The smouldering peat will cause a longer period of haze pollution.

Hence, groundwater is the only water supply in the study area that helps to reduce the smouldering effect. However, this groundwater highly concentrates Sodium Chloride (NaCl) since the study area is near to the coast. Figure 1 shows the location of the study area. Therefore, the concern of this assessment is about the migration of brackish groundwater in the aquifer materials. The salt intrusion in the aquifer system is investigated in Brunei, a neighbouring country of Malaysia and close to the study area [3]. The study area mostly covers the plantation land in Miri. Therefore, this research concern about the migration of brackish groundwater in the aquifer materials through existing drainages. The salinity of groundwater must consider to ensure the crops can survive under the present condition. The main objective of this assessment is to assess the subsurface condition of peat soil due to brackish groundwater seepage through drainages by using a numerical simulation.
2. Methodology
Several tasks are included in the research methodology. Visual MODFLOW is used to prepare the conceptual model and to simulate the groundwater flow and salt migration [4,5,6]. Input parameters of aquifer characteristics, sources of salt movement, and salt properties are databased in the software. A 3D visualization of simulation results is impressively produced. Besides, the software has a good user interface where the program is simple to use, understand, enhance and modify [7]. Figure 2 shows the sequent activity of the research study. Figure 3 shows the conceptual aquifer system representing the condition and parameter of aquifer materials in the study area. There are five layers of soil in the study area, namely peat soil, fined sand, clay, medium-grained sand, and silty clay. Table 1 shows the hydraulic conductivity (K), specific storage (Ss), specific yield (Sy), effective porosity (ne), and porosity (n) for different aquifer materials. Besides, this study also involves two rivers, namely Baram River, and Baong River. Besides that, the recharge value used in the simulation is 11% of the annual rainfall in the study area, which is 675.90 mm/year.
Figure 2. Activity chart.

Figure 3. Conceptual aquifer system.

Table 1. Aquifer material properties.

| Types of Soil          | $K$ (m/s) | $S_z$ (m$^{-1}$) | $S_r$ | $n_s$ | $n$  |
|------------------------|-----------|------------------|-------|-------|------|
| Peat                   | $3.23\times10^{-4}$ | $9.6\times10^{-6}$ | 0.44  | 0.4   | 0.83 |
| Fined Sand             | $2\times10^{-4}$  | $4.96\times10^{-4}$ | 0.33  | 0.2   | 0.40 |
| Clay                   | $9\times10^{-6}$  | $4.95\times10^{-3}$ | 0.06  | 0.11  | 0.46 |
| Medium Grained Sand    | $5\times10^{-3}$  | $4.97\times10^{-4}$ | 0.32  | 0.23  | 0.39 |
| Silty Clay             | $9.5\times10^{-6}$ | $4.95\times10^{-3}$ | 0.06  | 0.11  | 0.46 |
3. Results and discussion

The results include the calibration result, groundwater head, velocity vectors, and salt concentration migration in the aquifer materials, mainly peat soil.

3.1. Calibration result

Calibration is to minimize the root-mean square (RMSE) and maximize the correlation coefficient ($R^2$). The best RMSE value is less than 1 m, while the best $R^2$ value is closer to 1.

The calibration result shows a comparison between the observed head from observation in the study area and the calculated head from the simulation. The observation head represents the elevation of groundwater level in each pumping well. Table 2 shows groundwater heads of pumping wells for the calibration process. The figure 4 shows a slight difference between the observed and the calculated head. The figure shows that the RMSE value is 1.071 m, while $R^2$ is equal to 0.75. Hence, the boundary condition and parameters of aquifer materials in table 1 are acceptable.

Table 2. Groundwater head of pumping wells.

| Well No. | Coordinate (m) | Head (m ASL)* |
|----------|----------------|---------------|
|          | X              | Y             |               |
| KB3      | 171178.71      | 503597.25     | 4.5           |
| KB5      | 174509.55      | 503251.60     | 7.53          |
| KB7      | 172837.59      | 501819.51     | 6.9           |
| KB9      | 172277.26      | 500604.26     | 7.87          |
| KB15     | 169287.63      | 503672.68     | 3.526         |
| KB18     | 172446.28      | 495859.50     | 7             |
| KB19     | 169268.74      | 500582.73     | 5.3           |

![Figure 4. Calibration result of the simulation.](image)
3.2. Groundwater head
Figure 5 shows the movement of groundwater head in peat soil. The groundwater head flows from 10 m ASL at the east of the study area to 0 m ASL downstream of Baong River at the south. Besides, the groundwater heads are toward downstream of the Baram River at the north.

![Figure 5. Groundwater head distribution in the peat soil.](image)

3.3. Groundwater flow
Figure 6 shows the velocity vectors in the peat soil. The vectors move from the east of the study area to the north and northwest. Besides, the vectors also move to the west and southwest of the study area near Baong River. The maximum velocity magnitude is $7.5 \times 10^{-5}$ m/s.
3.4. Salt concentration distribution
The salt concentration results are estimated based on two conditions, natural and development conditions. The development condition is crucial for the research. The development condition is a condition where it involves pumping activities. The pumping activities is an abstraction of groundwater, and the pumped water fills the drainage system that helps to extinguish peat fire in the study area. Hence, the brackish groundwater from the pumping activities is expected to contribute to the migration of salt concentration in the study area.

Figure 7 shows the formation of a small plume below the drainage. The high concentration is possibly seen in the peat soil layer (layer 1) and fined sand layer (layer 2). Figure 8 shows the salt concentration of brackish water moves further down until the end of the clay layer (layer 3) after 2 years of pumping activities. The salt concentration is low as it moves down from the fine sand layer. Figure 9 illustrates the low salt concentration migrates further down until the middle of the medium-grained sand layer (layer 4) after 10 years of groundwater abstraction. The salt concentration stops migrating downwards as the times go on. However, figure 10 shows that salt concentration moves towards the coastal zone after 20 years. This is due to the directions of the velocity vectors as seen in figure 6. In figure 11, the high salt concentration moves down until the end of the clay layer, and the low salt concentration moves slightly more horizontally after 50 years. The salt concentration along the coastline is consistent from
Day 1 until 50 years of pumping activities. The clay layer shows a high salt concentration migrating inland until it reaches a certain point. The salt concentration for every layer becomes less as it migrates further inland. However, there is a formation of punching holes as the times go on.

**Figure 7.** Vertical distribution of salt concentration from the drainage in day 1.

**Figure 8.** Vertical distribution of salt concentration from the drainage in 2 years.
Figure 9. Vertical distribution of salt concentration from the drainage in 10 years.

Figure 10. Vertical distribution of salt concentration from the drainage in 20 years.
4. Conclusion
This study assesses the subsurface condition of the peat soil due to brackish groundwater seepage along the existing drainages by using a numerical method. Using Visual MODFLOW in this assessment has brought to the achievement of the objective. The results show there is only a small portion of high salt concentration along the drainage. The furthest that the salt concentration can migrate downwards is until the middle of the medium-grained sand layer as the times go on. Then, the salt concentration will move horizontally towards the coast, where the concentration decrease. The results show there is only a slight movement in the horizontal direction. The flow of brackish groundwater depends on the velocity vectors in every layer of soils. Meanwhile, the high salt concentration from the sea only concentrates along the coastline until it reaches a certain point. Then, the salt concentration reduces as it moves further inland. Therefore, the impact of brackish groundwater on the environment is not significant since the salt concentration is low in most of the study area.

5. Recommendation
A further study on the impact of salt concentration on the crops is one of the best recommendations since most of the study area is for plantation. This will help the plantation owner decides the best location to plant their crops. Besides, a study on designing drainage that able to reduce the salt concentration before it migrates into the aquifer materials is also one of the best recommendations. The selection of proper materials is crucial when designing the drainage system, so it will not pollute the environment.

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