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Groundwater Modelling of Leachate Plume by Using MODFLOW at Simpang Renggam Landfill

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Abstract: Landfilling method cause a major threat to groundwater resources. Simpang Renggam dumpsite was in a bad condition because overflow of leachate from a landfill during heavy rainfall and was in process to be closed due to reach the maximum capacity. This research study is to evaluate the potential of contamination risk due to leachate leakage at the landfill by using visual MODFLOW. The objective of this studies is to identify the groundwater contamination risk due to potential leachate leakage and seepage beneath the municipal landfill. The groundwater cannot be detected directly if they were polluted due to their condition underneath surface. However, using MODFLOW, the seepage of leachate from CEP Landfill was identified and able to detect the affected area surrounding groundwater resources in Simpang Renggam. The leachate plume movement was obtained and reach the surface water source that located at the low-lying area. Based on the result for COD and Ammonia concentration, the leachate plume spread widely in range 1 to 2 kilometers for Ammonia and 2 to 3.8 kilometers for COD at time steps 3650 days. The leachate plume also seepage into the aquifer with a depth of 30meters at time steps 3650 days for both concentrations. These results show the leachate from the landfill was already leak and reached the groundwater resources that can caused the soil and groundwater polluted. The concentration for both contaminants increases over time at the landfill and decrease when distance away from the landfill. Thus, this study shows that software of MODFLOW can be used for solving the same problem involved and can avoid other catchment area for being affected due to any other source of pollutants.

Keywords: Leachate, Groundwater Contamination, Visual MODFLOW, Simulation

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1. Introduction

Groundwater is hardly to be polluted but once it occurred the process of remediated the contaminants are difficult [1]. The groundwater needs to be treated carefully because it was alternative water resources after surface water. In Johor the water level of Machap Dam is at the critical stage and below the critical level. Machap Dam is the raw water sources of Simpang Renggam Water Treatment Plant and have been discharge for 25,894 consumers around Layang-Layang, Northern Pontian and Simpang Renggam. Due to this problem, the state government already prepared the water supply development plan for 50 years to avoid the water shortage in Johor. The state government realized the presence of groundwater resources can solved the problem of water shortage in Johor due to extreme and erratic global weather conditions. Even though, groundwater has an advantage of hardly to contaminated, the quality of water resources still needs to be monitored. This is because groundwater resources are stored beneath the ground surface and cannot be observe by direct method.

Landfilling method is the most method used to store and process of waste generated by increasing urbanization of humans and industries in Malaysia that can cause an environment pollution due to leachate generated from the landfill. This research study evaluated the potential contamination risk due to leachate leakage at the landfill predict the leachate flow movement though the water intake in the future by using visual MODFLOW. Visual MODFLOW is an indirect method that generally used in groundwater flow simulation program that can runs in any platform such as Windows and Linux. It also can use for monitoring and predict the contaminant transport. The simulation of groundwater flow by visual three-Dimensional model can solved the problem with the low cost and less time-consuming compare to direct method such as on-site investigation [2]. Visual MODFLOW also can be visualize results in 2D for cross section and plan view in development of the model. For complete three-dimensional groundwater flow and contaminant transport modeling, Visual MODFLOW is the most suitable software package had been offered [3].

In municipal solid waste landfills, the toxic substances are created from the combinations of non-toxic and slowly released into the surrounding environment over a decade. From those biological, chemical and physical process in landfills, it will be promoted degradation of waste and produce leachate and methane gases. CEP Farm Landfill was the main municipal solid waste landfill for area Batu Pahat, Kluang and Simpang Renggam. It has been operated for 16 years and already closed due to fully dumped and having a problem with overflow leachate. Moreover, Simpang Renggam Water Treatment Plant commonly facing the high amount of ammonia due to the overflow leachate from CEP landfill through the Ulu Sungai Benut. Johor are usually facing the water supply problem especially in the Simpang Renggam area due to the leachate contaminated surface water in Sungai Benut. In addition, the types of aquifer in Johor area are mostly alluvial aquifer. Thus, the emplacement of landfills over alluvial aquifers can becomes hazards to the groundwater. The spatial coincidence of those activities with the discharge areas of the alluvial aquifers generates an additional risk to the groundwater. Areas near landfills have a greater possibility of groundwater contamination because of the potential pollution source of leachate originating from the nearby dumping site.

2. Methodology

Software visual MODFLOW was used in modelling contaminant transport at Simpang Renggam Landfill. MODFLOW was able to simulate the contaminant transport through porous medium in 3-Dimensional modelling.

2.1 Software

MODFLOW 2000 is a computer program that developed by U.S. Geological Survey which simulates numerically the three-dimensional groundwater flow equation for a permeable medium by using a finite-difference method.

Model design in MODFLOW 2000 was prepared by input the parameter to state the conceptual model. The preparation of the model process starting from assign the initial boundaries condition of the model area to the hydrological input's parameter, geologic units and its properties

2.2 Methods

The process MODFLOW starting from obtain the data that consist of study area, data acquisition, model preparation and parameters, run and calibrate, verification and prediction, and last the output visualization shown in figure2.1.

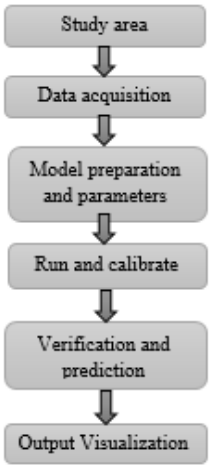


Figure 1: Flow of modelling process

2.3 Study area

CEP Farm Landfill is located in a southern half of Kluang District, Johor, Malaysia and it lies on between 1°53'40.5"N latitude and 103°22'34.9"E longitude. Location of landfill are nearest a town of Simpang Renggam which is 2km away from the town and 12km upstream from river. The main river of this study area is Sungai Benut, Sungai Sayong and Sungai Mengkibol. The total size of landfill in about 6 hectares. It can carry around 400-500 tons/day of the wet solid wastes [4]. They are covered for three area which are Batu Pahat, Kluang and Simpang Renggam every day. CEP Farm landfill has been operated for almost 16 years starting in 2003 as an open landfill and has been upgraded as sanitary landfill in February, 2016 but unfortunately has been closed in July, 2019 due to overflow leachate into a nearby river.

2.4 Leachate properties

The properties of leachate were referred based on the value of COD, BOD5, Turbidity, and Ammonia Nitrogen that presence in leachate. The parameter value of leachate in CEP Farm Landfill shown in Table 1 was used from previous studies as reference for this study. The transmission indicated that ammonia and COD were the highest concentrations and would be the most critical contaminants for groundwater resources. It will affect on irrigation and conservative with transport and time.

Table 1: Parameter of leachate sample from CEP Farm Landfill in 2017 [5]

Parameter	Average value
COD	1993 mg/L
BOD5	170 mg/L
SS	330 mg/L
Turbidity	181 NTU

pH	8.1
Ammonia	1000 mg/L
BOD_5/COD	0.085

2.5 Hydrogeology parameters

Table 2 was summarized the study aquifer input parameters for simulation model based on the hydrogeology properties obtained in this study area.

Table 2: Input Model Parameter

Parameters	Value
Hydraulic conductivity in longitudinal direction, K_x (m/sec)	1.28E-6
Hydraulic conductivity in lateral direction, K_y (m/sec)	1.28E-6
Hydraulic conductivity in vertical direction, K_z (cm/sec)	1.28E-6
Specific storage, S_s	1E-4
Specific yield, S_y	0.2
Total Porosity	0.3
Effective Porosity	0.15
Recharge (mm/year)	200 (10% of Annual Rainfall)
Recharge concentration of Ammonia(mg/L)	1000
Recharge concentration of COD (mg/L)	1993

2.6 Initial and boundary condition

A conceptual model for the study area was constructed with total effective area of 300.8 km^2, and model thickness of 34 m such in Figure 2. The model with surface distances of 17.8 km x 16.9 km where it extended toward the west and south to reach near to boundary conditions for Sungai Benut. The finite-difference grid model was constructed as in Figure 3 with uniform spaced as to represent the y-axis and x-axis and the point for elevation of study area. The grid was spaced grid in horizontal and longitudinal directions with consists of 1km per grid for row and columns. Based on the Figure 2, Sungai Mengkibol and Sungai Sayong were assumed as continuous because of similar of head value. It also to make sure the boundary was bounded and easy for MODFLOW system to read and translate.

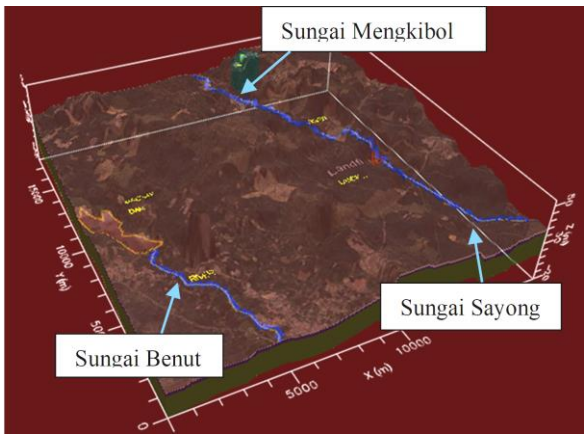


Figure 2: Conceptual model for the boundary condition at CEP Farm Landfill

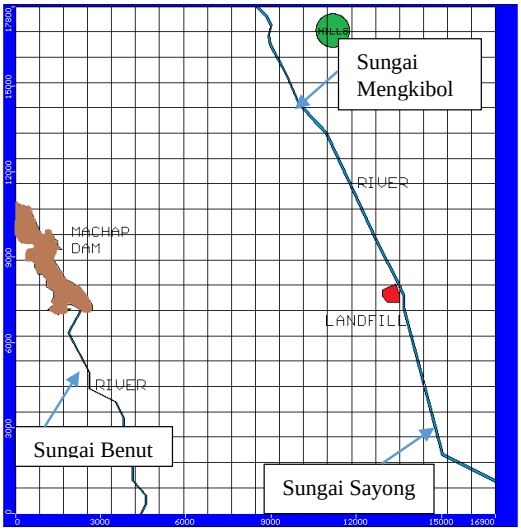


Figure 3: Boundary condition in a finite different grid line

2.7 Run simulation

The model was run to simulate the transient state condition by choosing three type of engines which are MODFLOW 2000, MODPATH and MT3DMS. MODFLOW 2000 was prepared a set of data for a transient flow simulation and automatically merge the time periods data defined for boundary condition into the stress period format. MODPATH assists with conceptualizing and evaluate the source zones for water entering the flow system, and flow going to groundwater system for the discharge areas. Meanwhile, MT3DMS is a modular 3-dimensional transport model that simulates 3D advective-dispersive transport of dissolved solutes in groundwater. The result will be shown as in Figure 4. After finishing the run of simulation, the output was adjusted the head and concentration contour colors range fitting for the value of head and concentration. Groundwater flow and contaminant transport simulation model was developed at the current year (2020) and then will be used for 10 future years prediction.

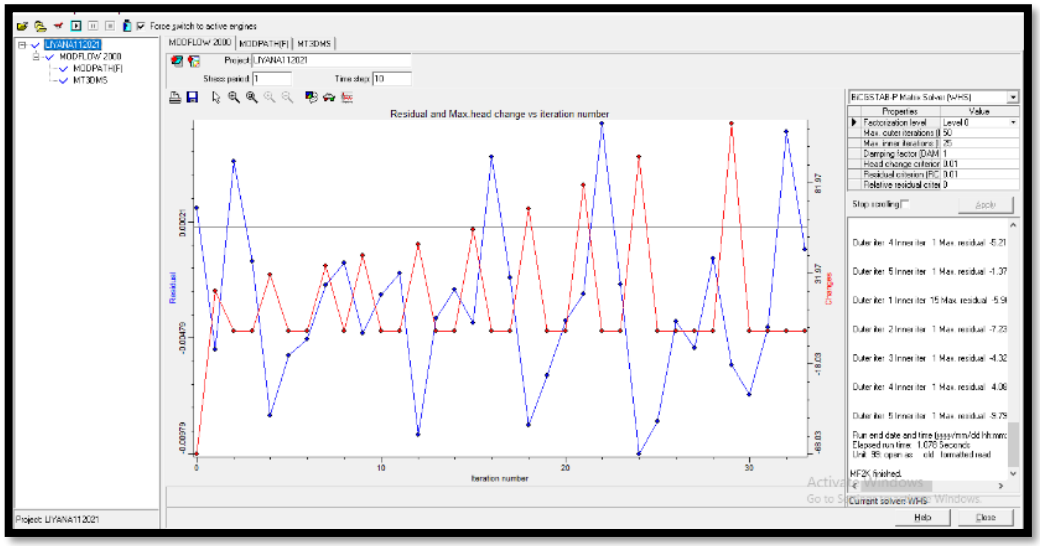


Figure 4: Finished result for run simulation

3. Results and Discussion

This section was describing the result obtained from the modelling simulation and discuss about the output result for leachate flows with concentration of ammonia and COD at CEP Farm Landfill.

3.1 Results

The result of this present study was showed the contaminants flow in groundwater flow direction and reached to water intake that located at the low-lying area. Under natural conditions, groundwater flow movement from the high elevation to the low elevation and towards rivers in study region. As shown in Appendix A the groundwater flow divide into two directions in the middle between the river at west and east because of the high elevation founded at the middle. The result come out with two different concentration which are COD and Ammonia. Based on the result for COD and Ammonia concentration, the leachate flows spread widely in range 1 to 2 kilometers for Ammonia and 2 to 3.8 kilometers for COD at time steps 3650 days. The leachate flows toward the north of the landfill and reach the water intake at the low-lying area.

Based on the concentration contour result, the value concentration of COD and Ammonia were obtained. The result of COD shows at the landfill area, the concentration increases at time step 3650 days with 900 mg/L from 600 mg/L at time step 365 days. Meanwhile, for Ammonia the concentration at landfill area increases from 500 mg/L to 700 mg/L in between at time steps 365 to 3650 days. However, the concentration for both contaminants decreases by a distance away from the landfill. The concentration of COD reached the water bodies at concentration 300 mg/L at time steps 365 days and 600 mg/L at time steps 3650 days. Meanwhile, the concentration of Ammonia reached the water bodies at the concentration 10 mg/L during time steps 365 days and 100 mg/L at time steps 3650 days. The concentration value for both concentrations still in the high value and stated under class V in Department of Environment (DOE) Standard for surface water bodies due to more than 2.7 mg/L for ammonia and more than 100 mg/L for COD.

3.2 Discussions

Creating 3D modelling using the old version software was difficult because they have a lot of bugs. The boundaries of the model need to define carefully to make sure the study area was bounded because it will affect on the output results and become dry cells. The main thing that important is elevation of study area. Even though the elevation of study area was imported correctly, certainly the data in software might different and not accurate as the imported elevation. However, this study was successful run the simulation after updating all those data and changing to suitable for their own set of water flow. Properties value such as of hydraulic conductivity (K), porosity, annual precipitation recharge, specific yield Sy and specific storage (Ss) was defined the groundwater flow and simulated its general direction.

The main objectives of this study were to identify the groundwater contamination risk beneath the municipal landfill and predict the leachate flow movement through the water intake in the future. The results indicated that the contaminant of leachate from the landfill was not disturbed the surface water bodies of Sungai Benut as in Appendix A. This is because the elevation between landfill and Sungai Benut are highest. However, the contaminants flow to the northeast where the low-lying area located. In this study, the contaminants flow in a direction of groundwater flow which is from the high to low-lying area. The leachate plume also seepage into the aquifer with a depth of 30 m at time steps 3650 days for both concentrations as show in Appendix D. These results show the leachate from the landfill was already leak and reached the groundwater resources that can caused the soil and groundwater polluted. The concentration for both contaminants increases over time at the landfill and decrease when distance away from the landfill. According to simulation results, concentration levels of leachate will remain to growth unless some action will be taken in removal the leachate.

3.3 Summary of Results

The result has been summarized in a Tables 3 and 4 for show the important details of the output results for both concentration of Ammonia and COD. It was described the result obtained from the modelling simulation and discuss about the output result for leachate flows with concentration of ammonia and COD at CEP Farm Landfill.

Table 3: Results of Ammonia concentration at 365 days and 3650 days

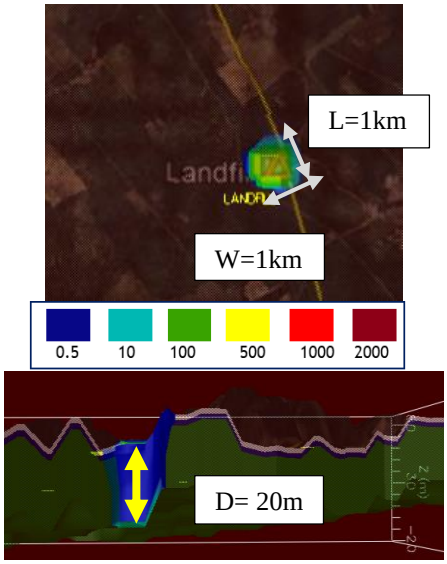
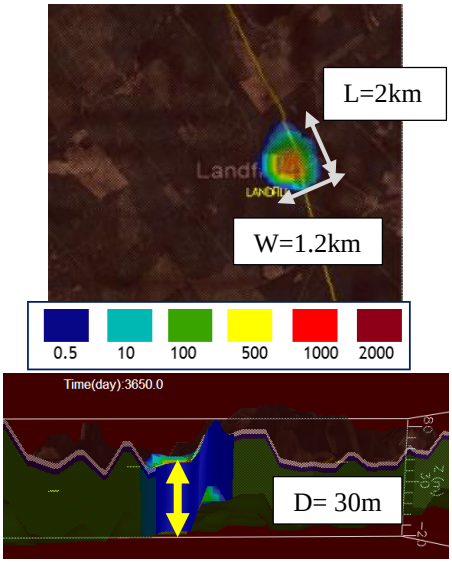
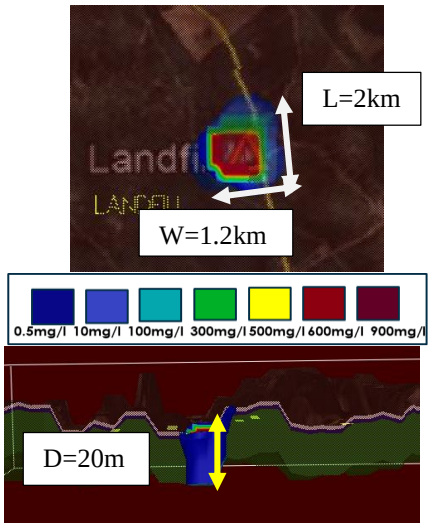
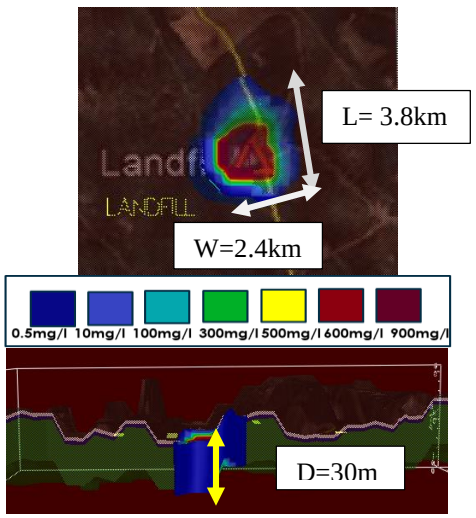
Days	365	3650
Leachate Plume Geometry		
Concentration	The concentration start migrates from 500mg/L-100mg/L in landfill and decrease away from landfill at 10 mg/L flow to the middle of river between Sungai Sayong and Sungai Mengkibol	The concentration at the landfill maintain in range 700mg/L-500mg/L but the concentration start increases to 100mg/L migrate away from landfill and reach to water bodies and flow toward north west based on the low-lying area compare at 365 days
Observation	The leachate plume dispersed with total length 1km and reached to aquifer with 20m depth.	The leachate plume increase to 2km length and seepage to aquifer with 30m depth
Ground Water conditions	Polluted	Polluted
DOE Standard	Class V (More than 2.7 mg/L)	Class V (More than 2.7 mg/L)

Table 4: Results of COD concentration at 365 days and 3650 days

Days	365	3650
Leachate Plume Geometry		
Concentration	The concentration start migrates from 600mg/L in landfill and decrease to 300mg/L to the middle of river between Sungai Sayong and Sungai Mengkibol	The concentration increases at the landfill in range 900mg/L and decrease to 600mg/L migrate to water bodies and flow toward north based on the low-lying area
Observation	The leachate plume dispersed with total length 2 km and reached to aquifer with 20m depth	The leachate plume increase to 4km length and seepage to aquifer with 30m depth
Ground Water condition	Polluted	Polluted
DOE Standard	Class V (more than 100mg/L)	Class V (more than 100mg/L)

4. Conclusion

The results were founded that there is a leachate leakage beneath the municipal landfill under depth 30 m in aquifers. Based on the results, it can conclude that the leachate already reached to the groundwater sources and cause polluted to the groundwater. The size of leachate plume was increased with time. The leachate plume migrates towards north direction of landfill which indicates at the low-lying area and in the direction of groundwater flow. In this study, the leachate flow movement in CEP Landfill was able to predict in time steps 3650. The visual MODFLOW was successfully used to simulate and predict the leachate movement in 3650 days. The model simulations show that the leachate concentration of the landfill area will remain increase over time if no future action. In conclusion, objective of this study was successfully achieved and can be used for future references.

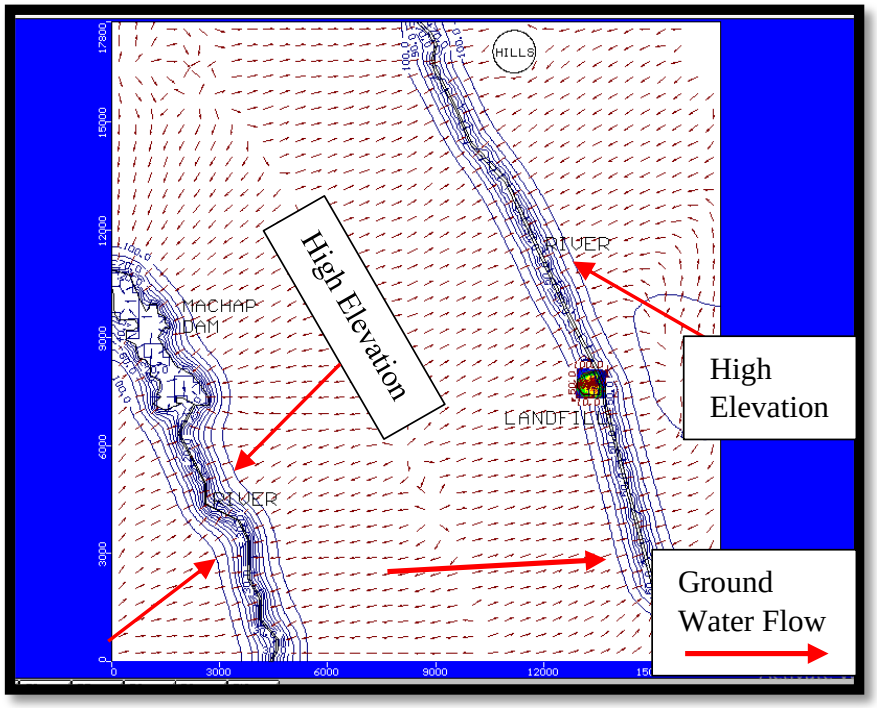
In order to prevent the soil and groundwater contamination, CEP landfill need to redesign the landfill by using non-permeable material such as clay to cover the landfill and prevent from the leachate leak to groundwater. However, there are few suggestions can be used for improving this study which are, to do an on-site investigation to obtain more data such as monitoring well to get more precise result and also use various pollutants such as heavy metals and organic compounds to describe the field condition precisely.

Acknowledgement

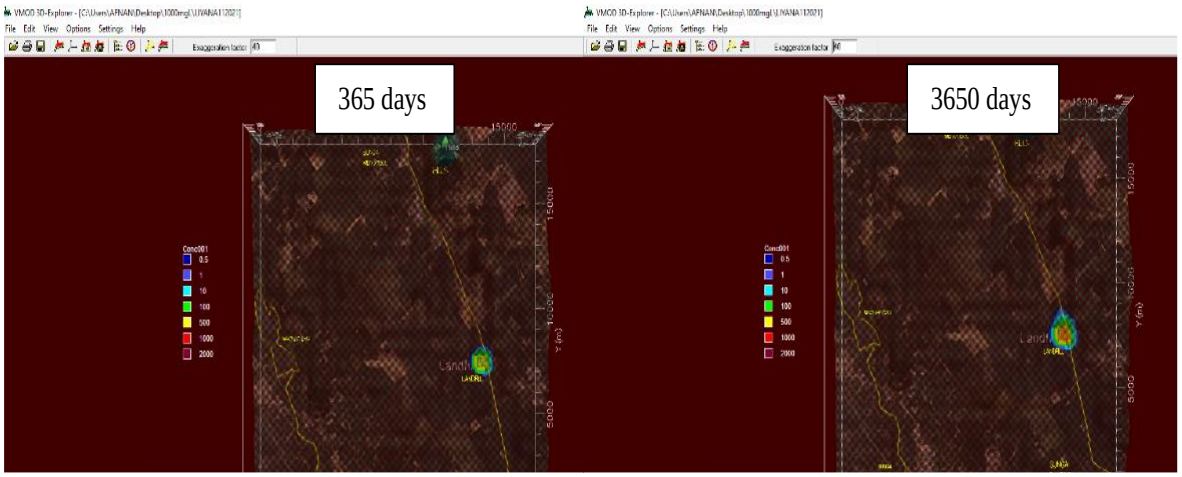
The authors would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for its support.

Appendices

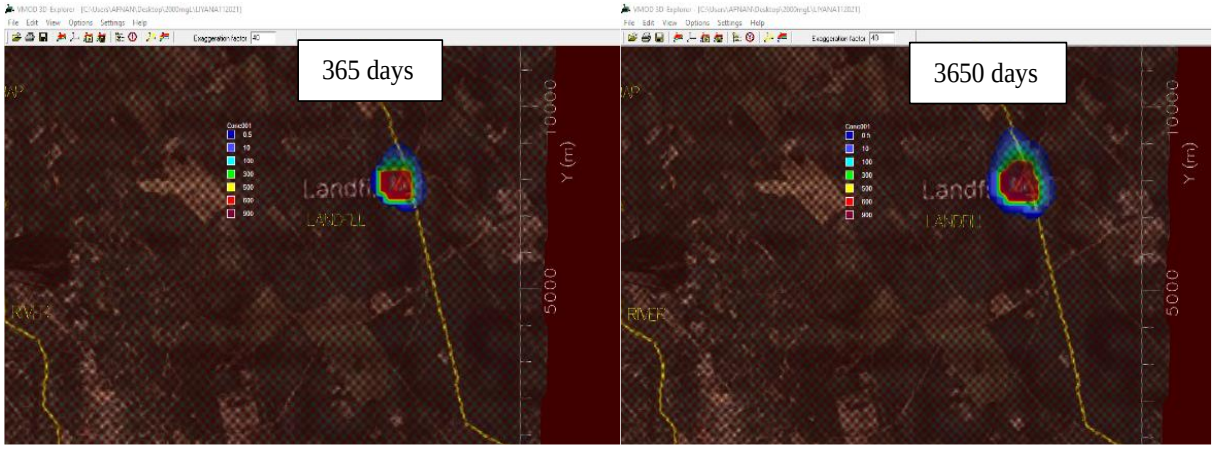
This section was provided the visual image of output from simulation results.



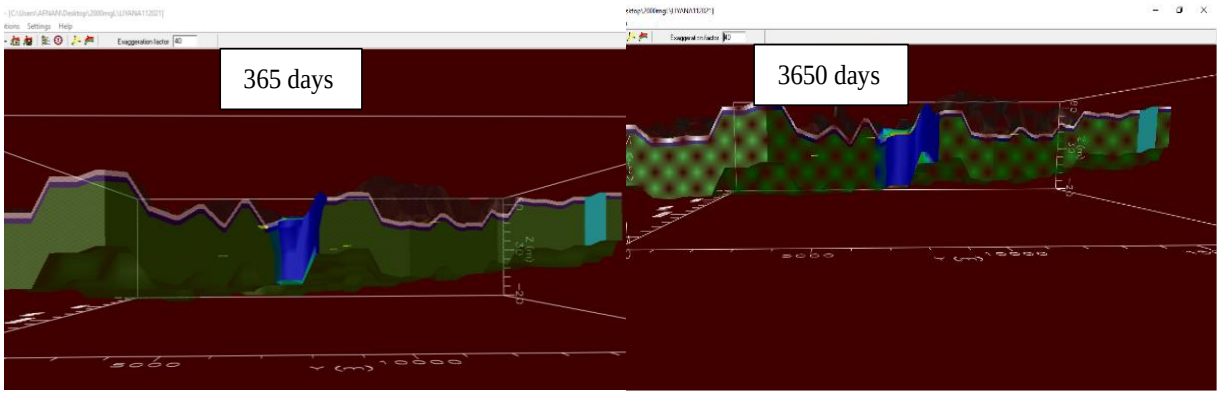
Appendix A: Directions of groundwater flow and velocity vector distribution for the aquifer at year 2020.



Appendix B: 3D output visualization for concentration of Ammonia transport from 365 days to 3650 days



Appendix C: 3D output visualization for concentration of COD transport from 365 days to 3650 days



Appendix D: 3D output visualization of the leachate seepage into the aquifer from 365 days to 3650 days

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