Numerical study on the effect of excavation dewatering on the contaminant emission in sandy soil

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Abstract. In recent years, construction has increased widely throughout the world, and the need for excavation and dewatering has increased dramatically. The potential for pollutants to enter soil and groundwater including chemical fertilizers, municipal landfill leachate, and hydrocarbons has also increased. The dewatering process used in the excavation can detrimentally affect the spread of contamination in the soil. In this study, the effect of different parameters on the emission of pollutants in different excavation depths has been investigated. Two software products SEEP / W and CTRAN / W are used for numerical modelling. The results show that the physical properties of soil have a significant influence on the contaminant movement. Also, it is indicated that the change in water level depth and the excavation depth have a massive effect on the contaminant migration process. Moreover, the vertical barrier can be an effective way to reduce the migration of contaminants to the excavation zone.

1. Introduction
Globally in recent years, construction has increased widely, and deep excavations have become more and more prevalent in construction projects. Excavation in saturated soil or in locations with shallow groundwater needs dewatering in order to construct in the pit. Water pumping and dewatering inevitably lead to pore water pressure changes and drop groundwater level in the surrounded supported ground [1,2]. This process can change the direction of the ground water flow in the surrounding area and draw the aquifer’s water into the pit.

Land is a precious resource and a critical component of the life support system of the earth, which unfortunately has been contaminated largely by many historical anthropogenic activities and industrial operations, including the production of chemical fertilizers, municipal landfill leachate, industrial waste discharges, etc. [3,4]. The release and spread of the contaminants into the soil may lead to intense health problems for humans as the contaminants can be absorbed through ingestion, inhalation, or dermal contact to the human body [5]. Accurate simulation of the pollution movement and solute transport in the soil environment is needed to apply efficient remedial technologies which are crucial requirements in geoenvironmental engineering and sustainability [4].

The movement of contamination in the soil is mainly controlled by the amount of contaminant present at the source, rate of release from the source, transport processes and hydraulic properties such as hydraulic conductivity, head gradient, water flow rate and direction [6]. Mostly, when a contaminant
released into the environment it may infiltrate through the vadose zone, reach the water table, and continue to migrate in the direction of groundwater flow [6,7]. Therefore, the contamination plume tends to flow along the same path as the ground water. The size, direction and flow rate of the pollution plume depend on the amount and type of contaminant, its solubility and density, and the velocity of the surrounding ground water. Therefore, the presence of excavation dewatering in the contaminated area requires seepage analyses of ground water in order to render a accurate prediction of pollutant migration. Contaminant transportation has been investigated in many researches [8,9]. Eltarabily et al. [7] numerically simulated the fertilizer movement in the sand. They applied SEEP/W and CTRAN/W software for their analyses and used vertical barriers to control the contaminant movement. On the basis of their results, the distance of fertilized transport considerably depends on the diffusion coefficient of contaminant Cation or Anion and hydraulic conductivity of the soil. At the overview performed by Patil and Chore [10], the numerical and experimental aspects of the contaminant emission through porous media were studied. They introduced a considerable number of studies and compared the emission results of pollution in saturated and unsaturated porous media. Sadiq et al. [11] Used advective-diffusion in their contaminant transportation simulations which were conducted via CTRAN/W sub-program. Javadi et al. [12] performed a numerical model to predict the two-dimensional transport of contaminants and water flow through unsaturated soils. In their model, a finite element method as well as a finite difference scheme was applied to solve the nonlinear system of governing differential equations, which was validated by standard experimental results. In the study conducted by Alsamia et al. [13] the distribution of landfill pollution in Al Najaf city was simulated by SEEP/W, and CTRAN/W to be controlled in order to prevent groundwater contamination. Their results showed the decrease in relative soil density has a significant effect on the contaminant penetration rate. Furthermore, the influence of fluid and soil properties such as permeability, void ration, and pollutant diffusion coefficient on the pattern of contaminant transportation in deep soil was investigated. The previous efforts also studied the movements of contaminant with respect to existing sheet pile in the soil, using numerical models [7,14]. Anderson and Mesa [14] used an impermeable circular arc with finite length as a vertical barrier wall to investigate its influence on the hydraulic control of contaminated groundwater. Their result indicated that the contamination movement can be slowed using the available large region of low discharge. In this study, the effect of excavation dewatering on the extent of pollution in soil has been investigated. In order to determine the factors affecting contamination transport by excavation and dewatering in different excavation depths, number of numerical models have been conducted. Two software products SEEP / W and CTRAN / W (available in Geo-Studio) are applied for this purpose.

2. Methodology and Numerical simulation

In this study, the effect of different parameters including water level depth, the use of a vertical barrier in different depths of excavation, diffusion, and Ky/Kx on the emission of pollutants in a place close to excavation has been investigated. For this purpose, SEEP/W and CTRAN/W software from Geostudio2012 are used. In the following, the details of each software are explained.

2.1. SEEP/W analysis

For analyzing pollutant emission, a steady-state analysis should be used to express the hydraulic condition of the area in the SEEP/W software. The curve of matric suction change vs volumetric water content is called the soil-water characteristic curve (SWCC). In this research, the characteristics of the SWCC are estimated by default software functions because details of grain size are not available. The parameters of sandy soil that use for this study are taken from reference [15]. Input data for the SEEP/W model are presented in Table 1 (coefficient of permeability, water content) [15]. SWCC and hydraulic conductivity curves are shown in Figure 1. Boundary conditions are specified as the total head (H = 30m), and the water level is on the soil surface. Model geometry, mesh dimensions are shown in Figure 2. The seepage flow velocities and pore water pressures (PWP) computed from SEEP/W are then used by CTRAN/W for the contaminant emission analysis.
Table 1. Soil properties used in the SEEP/W model [15].

| Parameter                                | Value               |
|------------------------------------------|---------------------|
| Saturated water content                  | 0.35                |
| Residual water content                   | 0.01                |
| Saturated hydraulic conductivity (m/s)    | 1.1574074e-06       |

Figure 1. (a) and hydraulic conductivity (b) SWCC.

Figure 2. Details of the numerical model.

2.2. CTRAN/W analysis
Contamination transport is controlled by two basic transport processes include advection and dispersion [15]. Advection refers to the process by which solutes are transported with the flowing water. Dispersion is the mechanical mixing and spreading of the contaminant from the flow system which causes dilution of contaminants both longitudinally, (in the direction of flow), and transversely (perpendicular to flow path) [16]. However, dispersion in the direction of the water flow is usually higher than dispersion perpendicular to the flow direction [17]. The advection-dispersion equation is, therefore, required to compute contaminant transport in unsaturated and saturated soil.

The model made in the SEEP/W software is transferred to the CTRAN/W software and, advection-dispersion analysis is utilized. At this stage, function characteristics of the pollutant, including diffusion, longitudinal dispersion, transverse dispersion, and properties of the soil, should be determined.
According to the Geostudio2012 guidebook, the longitudinal dispersion coefficient in laboratory and field-scale is generally equal to 0.1 of the length of laboratory or field dimensions. The transverse dispersion coefficient is assumed to be half of the longitudinal dispersion coefficient [17]. The boundary condition of the pollutant entry in the model is defined as a constant solute mass flux (1.1574074e-05 kg/sec/m²). Table 2 shows the parameters are used in the CTRAN/W model. Pollutant emission analysis has been done in unsaturated soil for three years.

| Parameter                  | Unit     | Value          |
|----------------------------|----------|----------------|
| Constant solute mass flux  | kg/sec/m²| 1.1574074e-05 |
| Longitudinal Dispersivity  | m        | 13             |
| Transverse Dispersivity    | m        | 7              |
| Diffusion                  | m²/s     | 1.1574074e-06 |
| Time                       | year     | 3              |
| Width of the model         | m        | 30             |
| Length of model            | m        | 130            |
| Mesh size                  | m        | 0.65           |

3. Results and discussion

3.1. Effect of excavation depth on the pollutant emission

In this study, we have investigated how the contamination depth and length are affected in sandy soil at different excavation depths. When soil is excavated, a hydraulic gradient is created which causes the steady-state flow to the excavation base. Figure 3 shows the total head, water table, water movement direction after 10-meter depth excavation.

![Figure 3. Total head distribution in 10-meter excavation.](image)

Water steady-state flow into the excavation causes the movement of plume toward excavation based on the advection-dispersion process. The results show that penetrating pollutant in-depth as well as the longitudinal expansion of pollutant increases by increasing excavation depth. According to Figure 4, by increasing the excavation depth up to 10 meters, the vertical penetration of pollutants goes up from
approximately 20 to 30 meters (reach the bed rock) after 3 years. Also, Figure 5 shows the longitudinal expansion of contamination plume in a variation of time and excavation depth. As it is illustrated, excavation dewatering increases the contamination transport towards excavation pit. Its effect increases when the time of excavation increases as well. The longitudinal expansion of the contamination plume goes up from almost 15 to 27 meters when the excavation depth is 2 meters and it goes up from almost 20 to 55 meters when the excavation depth is 10 meters. As you can see, by increasing the excavation depth, the rate of rising of length growing up significantly.

![Figure 4](image-url)  
**Figure 4.** The effect of excavation depth on pollutant emission. (a), (b), (c), (d), (e), and (f) show excavation depth of 0, 2, 4, 6, and 10 meters respectively.

![Figure 5](image-url)  
**Figure 5.** (a) Variation of contamination transport length vs time at different excavation depths (b) Contamination transport length in modelling software.

### 3.2. Effect of water level depth on the pollutant emission

When the water level is 5 meters below the surface, the soil above the water level is unsaturated. In unsaturated soils, pollutant emission does not only depend on permeability, and the SWCC curve is an essential parameter to propagation. According to Figures 6 and 7, by decreasing the water level, longitudinal expansion of pollutants decreases compared to that of surface water level. Rapid vertical
penetration of pollutants in the unsaturated soil can be due to high suction and high hydraulic gradient. By decreasing water content, matric suction increases, and soil permeability decreases. As Figure 7 illustrates, the plume is unaffected from excavation dewatering when excavation depth is above the water table because dewatering is not needed in such case, yet, in deeper excavations, the contamination plume is extended from about 21.5 to 44 meters which moves toward the excavation zone. However, it is not considerable compared to fully saturated soil (the contamination plume is extended from about 21.5 to 55 meters) because fewer hydraulic gradients are existing in the soil, and also, less contamination concentration can reach the water to migrate with the advection process. This signifies the fact that excavations dewatering affects the contamination transport when the water table is shallow or near the ground surface.

**Figure 6.** The contaminant movement with the water level of 5 meters below the surface. (a), (b), (c), (d), (e), and (f) show excavation depth of 0, 2, 4, 6, and 10 meters, respectively.

**Figure 7.** The contaminant transport length in a variation of excavation depth for ground surface water level and water level of 5 meters below the surface.
3.3. Effect of using a vertical barrier on the pollutant emission

Preventing the penetration of pollutants into the soil is one of the most important environmental concerns these days, which can be diminished via vertical barriers. In this section, a vertical barrier with a depth of 14 meters and a distance of 20 meters from the pollutant source point is used. As indicated in Figure 8, the results show that vertical barriers are effective and have reduced the propagation of pollutants remarkably. Figure 9 indicates the effect of the vertical barrier for excavation in a depth of 6 meters. As it is shown, the contamination transport towards the excavation decreases up to 60% after three years using the vertical barrier. As it is clear, the effectiveness of the vertical barrier increases over a longer period of time. The optimal depth and distance for the barrier can be calculated for each project.

![Figure 8](image)

**Figure 8.** The effect of vertical barrier on pollutant emission. (a), (b), (c), (d), (e), and (f) show excavation depth of 0, 2, 4, 6, and 10 meters, respectively.

![Figure 9](image)

**Figure 9.** The effect of vertical barrier on contamination transport length in variation of time for excavation with 6 meters depth.
3.4. Effect of the hydraulic conductivity and the ratio of $K_y/K_x$ on the pollutant emission

As hydraulic conductivity increases, the volume and water seepage into the pit increase which significantly augments the pollutant emission by advection process. As shown in Figure 10, when the soil permeability goes up, more contamination migrates toward the pit and the contamination plume increases considerably.

![Figure 10](image)

**Figure 10.** The effect of permeability on pollutant emission. (a) 50% permeability increase. (b) Base model. (c) 50% permeability decrease.

Also, as the $K_y/K_x$ ratio increases, the soil permeability increases in the vertical direction compared to the horizontal direction. As shown in Figure 11, with increasing $K_y/K_x$ ratio from 1 to 10, the penetration of pollutants into the soil depth has increased marginally. Also, the contaminate plume is more extended vertically.

![Figure 11](image)

**Figure 11.** The effect of $K_y/K_x$ ratio on pollutant emission. (a) Base model, $K_y/K_x=1$. (b) $K_y/K_x=2$, (c) $K_y/K_x=10$. 
4. Conclusion
In this study, the influence of excavation dewatering on contaminant transportation in sandy soil has been investigated. A parametric study has been conducted to evaluate the factors affecting contamination transport using SEEP / W and CTRAN / W finite element software. The results presented in this paper have proved the following conclusions:
1- By increasing the excavation depth, the hydraulic gradient which is created as a result of dewatering increases. This causes a considerable augmentation of 33% vertically and 175% horizontally in 10-meter excavation depth which tends to move toward the excavation.
2- When the water level is below the surface, the excavation has no significant effect on pollutant emission unless the excavation depth is below the water level in which the contaminant transport length can be extended to almost 105%.
3- Vertical barriers can play a pivotal key in the prevention of contaminant emission when there is an excavation in the contaminated area. Also, the effectiveness of barriers is more visible by-passing time when contamination plume is reaching it.
4- The permeability properties of the soil such as hydraulic conductivity and ratio of Ky/Kx can substantially affect the magnitude and pattern of the contamination transport in saturated soil with the presence of excavation.

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