Numerical and laboratory study of the way of municipal landfill leachate emission at unsaturated sandy soils

Abstract

Wide potential of entry of solid waste and landfill leachate in the soil and groundwater cause the way of its emission become an important subject. Since the release of the pollutant into the soil until it reaches the groundwater table, the soil is in unsaturated state, and at this time, the pollutant penetration into the soil is followed by primary matric suction of the soil and permeability. In this research the way of emission of municipal landfill leachate in the unsaturated sandy soil and also the effective parameters in emission and propagation of the pollutants are studied. For this purpose, numerical and laboratory modeling and also image analysis were used. The results of these experiments show that the release of pollutants in sandy soils is highly dependent on their physical properties. The results of numerical modeling show that when relative density of soil increase, the permeability and the depth of penetration of pollutants into the soil decreases. Also by decreasing the relative humidity of the soil, the depth of penetration of the pollutants in the soil increases and its longitudinal extension decreases. The results of numerical studies show that by increasing groundwater level to the soil level, the depth of penetration of pollutants into the soil also increases. Finally, using the image analysis method, we investigate the concentration change of pollutants in depth and compare it with the results of the numerical method. Results show that the image analysis method is able to estimate the concentration of the pollutant in depth with good approximation.

Key words: municipal landfill leachate, unsaturated soil, image analysis, emission pattern

1. Introduction

One of the important factors contributing to soil contamination is the disposal of solid waste and urban waste. However, the lack of proper system for disposal and the unsuitable design of waste landfill sites have led to concern about the penetration of oil and heavy metals into the soil. Pollution of the soil, in addition to contaminating groundwater table and endangering the health of humans and other living organisms, is also important in terms of environmental geotechnics. Due to the physical-chemical processes occurring between the soil and the pollutant, the resistance, permeability and compressibility of the soil may change, and therefore soil contamination may cause problems. In the following, we will discuss about them.

1.1. The basics of the pollution emission

The factors influencing on pollution emission in soil include two main processes: transport process and attenuation process. The transport process is presented by equations based on fluid flow rules. These equations, in combination with a series of mass balance equations that represent attenuation phenomenon in pollution emission in the soil, give us the main equation for the pollution emission in the soil. It should be mentioned that in this study, the attenuation process which involves adsorption and radioactive decay has been neglected and only the transport process has been investigated due to its high importance on pollution emission in the soil [1].

Transport process

Advection and dispersion are two main parameters in the transport of pollution. Advection is referred as the movement of the pollutant along with fluid flow in the soil between two points. Dispersion means to extend the area of pollution emission during fluid flow containing pollutant.

Formulation of pollution emission

Differential equation of pollution emission in the soil is presented based on mentioned mechanism in the previous section:

$$D = aV + D^{*} \qquad (1)$$

(٢)

$$(\theta + \rho_b K_d)\frac{\partial C}{\partial t} = \theta D_h \left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial Y^2}\right) - U\left(\frac{\partial C}{\partial x} + \frac{\partial C}{\partial y}\right) - \lambda(\theta C + \rho_b K_d C)$$

$$K_d = \frac{C_s}{C} \qquad (3)$$

Where, D_h is hydrodynamic dispersion coefficient in pollution emission (m^2/s), D^* is molecular dispersion coefficient, a is the amount of dispersion at porous medium (m), C is concentration of the pollutant in liquid phase in the soil medium in specific time and space (gr/m^3), x and y are space variable (m), t is time variable (s), U is apparent velocity of pollution flow in the soil, Θ is volumetric water content, p_b is soil density (kg/kg), K_d is distribution coefficient (m^3/gr), C_s is the concentration of the absorbed pollutant at solid phase (kg/kg) and ƛ is decomposition coefficient. These equations can be used in various numerical methods to calculate the amount of pollution emission. In this paper, numerical modeling of soil pollution emission has been done using the finite element method in the CTRAN Package and Geostudio Software.

1.2. Pollution emission

Sidle et al [2] were among the first researchers to use the emission equation to describe the movement of heavy metals such as copper, zinc and cadmium on a forest soil in 1977. Hellweg et al [3] investigated the processes affecting absorption and creating delay on the movement of heavy metals through soil column testing, and introduced the most important parameters for absorption, surface deposition and surface composition in 2003. In 2003, Mohammadi and Mousavizadeh [4] investigate numerical and laboratory study of NAPL diffusion in the soil. They performed experiments for obtaining physical properties of soils such as permeability, soil-water characteristic curve, water content and dry density. Their model consists of 3 layers of soil. Upper layer and lower layer are composed of sand and middle layer is contained fine-grained soil. In 2007, Al-najjar and Javadi [5] presented a numerical model for simulation of air, water, and pollutant flow at unsaturated soil and concentrated on effects of chemical reactions. Governing equations for mixable pollutants is presented including emission effect, diffusion, dispersion and adsorption. Comparison of numerical model results with experimental results showed that the numerical model was able to predict the effects of chemical reactions with high accuracy. In 2010, Persi et al [6] examined the transport flow of hydrocarbon pollutants leaked from fuel storage tanks in unsaturated soils. To this end, they selected fuel storage in Brazil to develop their analytical model and assessed the role of soil permeability and pollutant characteristics on the transport flow. Chotpantarat et al [7] in 2012 empirically determined the movement of heavy metals in single, dual and multiphase systems through soil columns, and then modeled it by HYDRUS software using the local transport balance (CDeq) or first order kinetics non-balance chemical dual spatial model (TSM). In 2013, Guangyao et al [8] presented one-dimensional equation for the emission process in the soil with depth-dependent reaction coefficients and depth-dependent boundary conditions. Absorption coefficients and erosion rates were shown as uniform explicit and decreasing functions of soil depth. Jeong and Charbeneau [9] in 2014 introduced an analytic model for predicting the way of light hydrocarbon pollutants distribution and different methods for purification. They investigated one purification method using pumping wells (LDRM) and also developed their analytical model for heterogeneous soil up to three layers. In 2015, Eltarabily et al [10] investigated the movement of nitrates in different soils and also studied the use of vertical barriers for pollution control. In this research two finite-element software called CTRAN/W and SEEP/W for analyzing pollution emission. Results show that physical properties of the soil have main effect on pollution emission. In 2015, Faisal and Thien [11] investigated influential factors on landfill leachate emission. Studying site was in the region near the landfill. In the underground water of that area, high amount of heavy metal combinations were found. Parameters including saturation hydraulic conductivity coefficient K_s, longitudinal dispersion coefficient D_L, soil adsorption coefficient K_d, and transport water coefficient D_w are studied. Also they used the heavy metal such as copper and zinc for leachate compounds. They concluded that soil absorption coefficient is the most important factor for leachate diffusion into soil. Pazoki et al in 2017 [12] carried on researches about numerical simulation of municipal landfill leachate in the soil. They investigated the emission of landfill leachate in the Aradkouh city in the soil, as well as prediction of changes in the concentration of nitrogen and phosphorus in the leachate at various depths.

1.3. Image analysis

Civil engineering, like other fields of science and engineering, has employed image analysis (D.I.P) techniques. In recent years, studies have been carried out on D.I.P, almost in each section of civil engineering branches. D.I.P methods have been used to evaluate the stress situation in the pavement, to measure the morphological parameters of the materials, to reveal specific specifications in composite materials, to study the crack propagation process, or the patterns of material fracture, as well as the supervision and inspection of engineering structures. Van Geel and Skeys [13] carried on a series of multiphase experiments in the laboratory. In these experiments, the capillary pressure recorded by barometers was used to calculate the saturation of different phases. Also, the results of these experiments showed that the capillary pressures and saturation vary for short periods of time and for the times of arrival of pollutant to the barometers. Kue et al [14] in 1996 used a transparent L-shaped tray to get the imaged surface of the aggregate particles. The L-shaped tray was rotated 70 degrees to measure particle height. In this method, the size of aggregate particles as long, medium and large are obtained. These measurements provide direct data on particle flatness and elongation. Person [15] in 1998 presented a method based on D.I.P to study the shape and size of aggregate. In this method, the difference between washed and natural materials was analyzed based on different images. In 1999, Ghalib and Hryciw [16] presented a method for morphological zoning to separate soil particles. Diamond and Huang in 2001 [17] combined image analysis based on D.I.P and image analysis which is obtained by SEM in concrete cement to study the effect of ITZ (the transport area is created in mixing concrete stage due to forming spaces full of water around the aggregate). SEM-DIP showed that porosity in the volume of cement paste in well-mixed concrete is about 6 to 9 percent. Peterson in 2001 [18] evaluated the characteristics of empty spaces of cement concrete surface using the D.I.P methods quantitatively. In 2000, Reid and Harrison [19] used methods based on D.I.P to detect the geometric discontinuity of rock mass. In these methods, three criteria (neighborhood measure, orientation, and lighting measure) were proposed for linking this discontinuity to the lines. In 2003, Corthesy and Leite [20] used methods based on D.I.P to detect rock slope motion. In these experiments, photographs are taken from identical locations at different time intervals.

All studies on this subject emphasize that the pattern and method of pollutants emission into the soil strongly depends on the physical properties of the soil and the pollutant, however, in some studies, the effect of each of these parameters has been investigated separately (for example permeability coefficient), which requires a closer look due to the unsaturation of the soil and the effect of matric suction in the time of emission and the non-independence of the parameters from each other.

2. Laboratory tests

In this study, a rectangular cube model with dimensions of 80 × 8 × ١٢٠cm^3 was constructed in order to investigate the way of municipal landfill leachate at unsaturated soils and to estimate its concentration in depth So that pollutant penetration can be observed well. The reason for the low thickness of this model is to better investigate the spread of pollutants in the length and width of the soil. It also reduces the error in modeling with the two-dimensional Geostudio 2012 software. Two valves are embedded on the bottom of the tank in order to saturate and regulate the groundwater level. The valves are covered with geotextile cover to prevent the sand from being washed during water enter and exit. The sand used in this experiment is the 131 standard Firoozkoh sand and its specifications are given in Table 1. This test was carried out in two unsaturated sections in drying direction, each section includes four tests. In each test, soil has reached to one of the densities 40, 60, 80 and 100%. The Rainer system with a dispenser sieve was used to fill the test tank. This device can produce uniform samples with relative density 20-115%. In this test, the pollutant is penetrated into soil 3 cm by glass rectangle cube with dimensions 20×7×3 and fixed head. The test has continued until the arrival of pollutant to the end of the glass tank and photographs were taken from pollutant at 5, 50, 150 and 250s. Figure 1 shows schematic view of the Rainer system and test tank.

Figure1. Schematic view of the Rainer system

Table1. Permeability test

The soil permeability against the leachate was measured by the fixed head test by formula 3. A volumetric balloon was used to measure the specific gravity of the pollutant and its value was measured 1.2g/cm^3.

$$K = \frac{QL}{Aht} \tag{4}$$

In this case, K is the permeability coefficient of the soil (m / s), Q is the volume of output water over a given period (m^3), L is the distance between the two outlets on the cylinder from the center of the porous (m), A is cross-section area of the soil sample (m^2), h is the difference in water level between the two piezometers (m) and t is the time required to measure the output water (s). Figure2 shows the Permeability variations against relative density variation of the pollutant.

Figure2. The diagram comparing permeability variations against relative density variation of the pollutant in different density of the soil

2.2. Capillary level measurement

To perform laboratory tests and to lower the level of water to the desired level, it is necessary to calculate the capillary height. In fact, the observed water level in this experiment is apparent and is the combination of true water level and capillary level. To calculate the capillary level, a small-scale laboratory model $40 \times 8 \times 20\ cm^3$ was constructed and a valve was embedded below it for water entry and exit. To observe the actual water level, a transparent tube is installed in the corner of the tank to get the actual water level. Table 2 shows the capillary level in the desired densities.

Table2. Pollutant capillary level in different densities of the soil

2.3. Leachate construction method

Several definitions and classifications have been presented to explain municipal wastes. Municipal waste includes food waste, garbage (non-decomposable waste such as glass and plastic), waste resulting from the building and special wastes (dead bodies of animals). Food waste is the most important part of the waste because it produces an unpleasant odor due to fermentation and rapid decomposition, and it is a suitable place for the growth and proliferation of various bacteria, fungi and vermin and, on the other hand, it is important due to the ability to produce fertilizers from it (compost) [21]. The most important compound in the leachate of the food waste includes proteins, carbohydrates, vegetable waste, and fats [22]. The compounds of municipal landfill leachate are very variable and there are more than 200 organic compounds in these pollutants [23]. In this study, in order to maintain the conditions and repeatability of the tests, used combinations of leachate must be same as possible. For the production of leachate, the weight of each is prepared and combined. In this study, chicken skin was used as a source of fat and protein, bread as a source of carbohydrates, vegetables and watermelon peel as a vegetable source.

At each stage of leachate production, given material are poured in layer order and stored for up to ۱0 days in a warm and dark place. After 10 days, the leachate was taken. Finally, obtained leachate was poured in clean fabric bag to be completely pure and desired leachate produced for the test. In every stage of the test, 4 liter pollutant is required. The pollutant contains 3.8l waste leachate, 100cc edible red color and 100cc water. In this research, diluted red leachate was used as a pollutant. Use of red color is to see better penetration of the leachate into soil. For performing each test, 11 days before the test the process of the leachate production was done. Therefore, used leachate is 11-day-old in each test.

2.4. Test in unsaturation state in drying direction

In this part of the experiment, after filling the glass box up to 60 cm, the valves of the bottom of the box are opened so that the sample is completely saturated. After saturation, the box is left for 24 hours to remove all air bubbles. Then, by opening the bottom valves, the surface of the water is brought down to a height of approximately 10 cm from the bottom of the box (by regarding the capillary level). The experiment was performed after 48 hours to balance the water level and moisture inside the soil. Figure 3 shows the way in which pollutants penetrate into different densities at a given time. Longitudinal pollutant expansion at this time is presented in Table 3. As the density increases in unsaturated soils, the longitudinal pollutant expansion increases. Table ۴ shows the arrival time of pollutant to the groundwater in 4 tests performed in unsaturated state. Diagram 4 shows the duration of pollutant penetration in different soil densities.

Figure3. the way of pollutant emission in 150s in different densities a)40, b)60,c)80 and d) 100% in unsaturated soil.

Table3. Longitudinal pollutant expansion in 150s in different densities of the unsaturated soil

Table4. Arrival time of pollutant to underground water in different densities of the unsaturated soil

Figure4. Chart of time of penetration pollutant in different densities of the unsaturated soil

2.5. Test in dry state

In this part of the experiment, after filling the glass box up to 60 cm, the valves of the bottom of the box are opened so that water reaches to desired height by regarding the capillary level). The box is left for 24 hours so that the soil reaches to balance. In unsaturated state, porous water pressure in the soil is considered linear, but in dry condition, PVC tube in 3 cm diameter was used to sample soil in the box and moisture content is calculated at different depth to obtain moisture profile before the test. Figure 6 show the profile of percent moisture in depth of the box. Figure 5 shows the way in which pollutants penetrate into different densities at a given time. Longitudinal pollutant expansion at this time is presented in Table 5. As the density increases in the dry soil, longitudinal pollutant expansion increases. Table 6 shows the arrival time of pollutant to groundwater in 4 performed tests in dry condition. As relative density of the soil increases, the time of pollutant arrival to underground water increases too. Figure 7 shows duration of penetration pollutant in different densities of the soil.

Figure5. The way of pollutant emission in 150s in different densities a)40, b)60,c)80 and d) 100% in dry soil.

Table5. Longitudinal pollutant expansion in 150s in different densities of the dry soil

Table6. Arrival time of pollutant to underground water in different densities of the dry soil

Figure7. Chart of time of penetration pollutant in different densities of the dry soil

2.6. Comparing the tests in unsaturated and dry soil

Amount of matrix suction in unsaturated soils is a function of water content in the soil. As the water content increases, the matrix suction decreases and as soil water content decreases, the matrix suction increases. The curve of matric suction variations with soil volumetric water content is called soil-water characteristic curve or SWCC. Figure 8 shows one example of SWCC. One of the important features of the SWCC is that the variations in degree of saturation in drying direction and the variations in degree of saturation in wetting direction are not placed in the same direction. In the other words, SWCC is hysteresis hydraulically. This case is shown in figure 9. In other words, in order to determine the degree of saturation, such as defined suction, it must be clear that the soil is in the drying direction or wetting direction [23].

Figure8. SWCC Curve

Figure9. Hydraulic hysteresis in unsaturated soil

According to figure10, permeability variations are also hysteresis based on matric suction. In other words, K_w shows two different values based on whether suction is in state of the adsorption of the water (wetting) by the soil of or in the state of missing water (drying).

Figure10. The permeability coefficient variation K_w with matric suction

In figure10, K_s is saturation permeability coefficient and K_W is unsaturation permeability coefficient.

Figure11 shows the comparison of the way of pollutant penetration in different densities in 2 dry and unsaturated states.

Figure11. The curves of the comparison of the way of pollutant penetration in different densities in dry and unsaturated soils with a)40, b) 60 ,c)80 and d) 100% density.

According to the results of the experiments, it can be seen in the dry soil, the pollutant penetrates faster than unsaturated soil. The rate of penetration of pollutants in the soil depends on the two suction parameters in the soil and the multiplication of the permeability coefficient in the gradient or energy. Rapid penetration of pollutants in the soil can be due to high suction and high gradient or energy which is caused by the difference in heads in the dry soil. Figure2.5. shows the longitudinal expansion of pollutant in unsaturated and dry soil with different densities.

Figure12. The curves of the comparison of the way of longitudinal expansion of pollutant in unsaturated and dry soil with different densities: a) 40, b) 60 ,c)80 and d) 100%

According to these curves, the longitudinal expansion of the pollutant increases over time. The increase in the longitudinal expansion in the unsaturated soil is more than the dry soil. In fact, the longitudinal expansion of the dry soil changes slightly over time.

3. Numerical modeling

In this research, SEEP/W and CTRAN/W packages and Geostudio 2012 Software are used to model pollution emission.

3.1. Modeling in SEEP/W medium

In SEEP package, Density-Dependent Analysis which is as couple of CTRAN and SEEP should be used to analysis emission and for pollutants with relative density except one. In order to investigate the emission of the pollution in a porous medium such as soil, a model should be constructed in the SEEP environment whose main task is to express the hydraulic conditions of the area under investigation. Firstly, in the SEEP environment, the dimensions and geometry of the model are created. After designing the geometry of the model, the specifications of the materials in the soil environment are defined. In this research, as mentioned in the previous sections, permeability is calculated by experiment with fixed head in the laboratory and the characteristics of the water-soil maintenance are also designed by soil aggregation. Mesh analysis should be done by trial and error in order to obtain proper dimensions of the meshing. In the final step, the boundary conditions of the pollutant entering the soil should be specified. In the first model, boundary conditions with fixed head and in the second model, boundary conditions with constant discharge flow are considered. After performing the above steps, the SEEP model is made and ready to transfer to the CTRAN medium and to adjust the various pollutant parameters and emit it in the soil environment.

3.2. Modeling in CTRAN/W medium

At this stage, the model made in the SEEP package is transferred to the CTRAN environment, which is done automatically in the used software version. At this stage, the characteristics of the pollution functions, including diffusion, adsorption, longitudinal dispersion and transverse dispersion properties of the soil should be determined. The amount of diffusion coefficient is considered according to studies by Jeff [24]. It should be noted that according to the Geostudio guidebook, the longitudinal dispersion coefficient in laboratory and field scale is generally equal to 0.1 of the length of laboratory or field dimensions. Also, the transverse dispersion coefficient is assumed to be less than the longitudinal dispersion coefficient and about half of it. Finally, we must define the existing boundary conditions of the pollutant in our model. Then, after these steps, the model can be analyzed by specifying the time steps.

4. The first numerical model

In this section, according to given descriptions for simulating the experiment conducted by Geostudio 2012 software, first, a model with 60 × 120 cm 2 dimensions is defined in accordance with the software model and the soil characteristics according to Table 7 and 8 in the model Numerical value is used. The water-soil characteristic curve is estimated according to the sand aggregate specification in Table 1. The amount of diffusion coefficient for municipal leachate estimated by Jeff [24] was 10^9 and also according to the Geostudio Guidebook, the values of the longitudinal and transverse dispersion coefficients were considered 0.12 and 0.06 respectively. As shown in Fig. 14, the mesh dimensions are considered as 0.02 m as square and with 9 Gaussian points by respecting to mesh studies in order to obtain the appropriate precision in problem solving and avoidance of complexity. In this research, pollutant emission analysis has been done in dry and unsaturated soil after 5, 50, 150, and 250s. Water-soil maintenance curve is according to figure 13 in this modeling.

Figure13. Water-soil maintenance curve in unsaturated state for 131 standard sand of Firoozkoh

Table7. Used information in the numerical modeling

Table8. The characteristics of studied soil in numerical modeling

Figure14. The curves showing the variations in penetration depth of pollutant and longitudinal expansion based on changes of mesh dimensions in the numerical model.

4.1. Unsaturation state

For example, Figure 15 shows a comparison the way of the pollution emission in a numerical model and laboratory model at 100% density. In the following, in Figure 16 the comparison of the results of numerical analysis and laboratory test for all densities is presented. In all investigations, D is the penetration depth and L is longitudinal expansion.

Figure15. Comparison of pollution emission in laboratory model and numerical model at unsaturated soil with 100% density at times: a) 5, b)50, c)150, and d)250s.

Figure16. The curve for the comparison of the results of numerical analysis and laboratory test in unsaturated soil for densities: a)40, b)60 , c)80,and 100%

2.4. Dry state

In dry condition, with availability of water content profiles in depth and using formulas 5 and 6 , volumetric water content can be calculated at each depth of percentage of desired densities . Head of water negative pressure is obtained by soil-water characteristic curve [23, 25]. For example, Figure 17 shows a comparison the way of the pollution emission in a numerical model and laboratory model at 100% density. In the following, in Figure 18 the comparison of the results of numerical analysis and laboratory test for all densities is presented.

$$Sr\,.W = Gs\,.e \qquad (5)$$

$$Sr\,.n = \theta \qquad (6)$$

Where, S_r is degree of saturation, w is water content, e is void ration, G_s is specific volume, n is porosity, and Θ is volumetric water content. In the following, the results of the model analysis in various densities with CTRAN / W software are shown, respectively, and the comparison curve of the numerical and laboratory models is plotted.

Figure17. Comparison of pollution emission in laboratory model and numerical model at unsaturated soil with 100% density at times: a) 5, b)50, c)150, and d)250s.

Figure18. The curve for the comparison of the results of numerical analysis and laboratory test in unsaturated soil for densities: a)40, b)60 , c)80,and 100%

According to the curves, the results in numerical and laboratory states are consistence at acceptable level. By increasing soil density, the consistency of the results will increase in terms of penetration and emission type. By increasing the soil density, the transverse expansion of the pollution decreases. For example, at 150 seconds, with Change the density percentage of 100 to 40%, the penetration of the pollutant into the soil increased by about 13 cm.

5. The second numerical model

In order to expand the results and carry out further studies on the way of distribution of municipal landfill leachate, the effects of parameters such as relative density, groundwater level and changes in the dispersion coefficient of pollutants in a soil environment at depth of 30 meters and a height of 20 meters have been investigated. It should be mentioned that L and D parameters which are transverse dispersion and longitudinal dispersion respectively are measured with 0.1% concentration related to tank. In this section, two type of soils including sand and silt clay. Assumed parameters in the modeling are presented in tables 9 and 10.

Table9. Used information in numerical model

Table10. The characteristics of the given soil in the numerical model

The amount of WC is calculated using Geostudio 2012 according to figure19.

Figure19. The functions of SWCC curve as presupposition in Geostudio 2012 Software.

5.1. Analysis of effect of relative density of pollutant

In this section, the results of the variation of the relative density of the pollutant are reviewed. For this analysis, considering the relative density of the municipal landfill leachate is more than1, the amount of relative density of the pollutant is considered 1-1.8. In the following, the way of pollution emission with different densities over time foe coarse and fine soil is discussed.

Figure20. The curve for the effect of the relative density changes of pollutant on penetration depth in coarse soil

Figure21. The curve for the effect of the relative density changes of pollutant on penetration depth in fine-grained soil

Regarding figures 20 and 21, by increasing relative density, the penetration depth increased due to the increase of the weight force of the pollutant. For example, pollutant with relative density 1.8, penetrated 14m in the soil after 40 days, while this value is 11m for pollutant with 1.1 relative densities. As seen in figure 21, the change of pollutant density in density range more than 1, has slight effect on fine-grained soil.

Figure22. The curve for the effect of relative density changes of pollutant on longitudinal expansion in coarse soil

Figure23. The curve for the effect of relative density changes of pollutant on longitudinal expansion in fine-grained soil

Considering figure 22 and 23, it was determined that change in relative density has slight effect on longitudinal expansion of the pollutant in the surface of the soil and this effect is very intangible in fine-grained soil.

2.5. Analysis of groundwater level effect

This section examines the effect of groundwater level change on pollutant emissions. Modeling in the software has been done according to the specifications of Table 9and 10 for fine-grained and coarse-grained soils. Groundwater level is considered as 5, 10, and 15m from the surface. Two pollutants with relative density 1.1 and 1.8 is used for better understand the effect of the groundwater level. In the following, the curves for changes of penetration depth and longitudinal expansion of the pollutant in soil media are presented. In all the curves, penetration depth and longitudinal expansion of the pollutant has measured 30 day after emission.

Figure24. The curve for the variation of the penetration depth of the pollutant in time with the change of groundwater level in coarse-grained soil

Figure24. The curve for the variation of the penetration depth of the pollutant in time with the change of groundwater level in fine-grained soil

Figure24. The curve for the variation of longitudinal expansion of the pollutant in time with the change of groundwater level in coarse-grained soil

Figure24. The curve for the variation of longitudinal expansion of the pollutant in time with the change of groundwater level in fine-grained soil

As shown in the curves, the effect of groundwater level changes in fine-grained soils is lower. Coarse grains have high permeability and drainage properties. Therefore, when the groundwater level decreases, the soil surface has lower water content and matric suction increases, which causes the penetration of the pollutant into the soil. For example, in a pollutant with a relative density of 1.8 after 50 days, the pollutant in the soil with a groundwater level of 5 m and 15 m penetrates 11.5 and 16 meters in soil respectively. The fine-grained soil has low permeability and therefore they conserve water content with change in groundwater level and finally there will be no significant change in diffusion rate of the pollutant. Also, by reaching pollutant to groundwater, the rate of its penetration decreases due to distribution of the pollutant in the water.

6. Image analysis

In this step, MATLAB software is used for image analysis. Images taken from the emission of leachate into the soil are inputs and the curves for showing the way of change the intensity of the color versus the pixel are output. First, an initial image of the test box and the lighting conditions are taken before the leakage event, and then taking image is repeated at each stage of the leakage at different times. In this way, it's important to be careful that the light conditions are the same for all the images. Photos taken in black and white are examined and a range of colors from gray to black is defined as zero to one hundred concentrations. In this range 0 show the black and 255 show the white. For image analysis, first the image was taken to HSV and RGB space and they were binary. Average and Median filters were used for removing image noise. Figure 28 show the HSV and RGB space and figures 29-34 show the function of the filters. After plotting the color intensity of the image analysis method (Fig. 35), it is necessary to convert this curve to the curve of concentration change relative to the depth. To do this, it is necessary to give 100% concentration to the highest color intensity for each curve, and the 0% concentration to lowest color intensity of each curve. Because of the noise in the existing curve, it is necessary to fit a linear function and compare it with the concentration curve from the Geostudio2012 software.In this method, an indirect distribution of pollutant concentrations can be obtained indirectly. The curve of depth changes is presented by Geostudio2012 software as shown in Figure 36.

Figure28. Representation of RGB and HSV space

Figure29. Display of given image in binary state

Figure30. Use of HSV filter on binary image

Figure31. Use of RGB filter on figure30

Figure32. Use of Median filter on figure31

Figure33Use of Average filter on figure32

Figure34. Display of pollution emission area

Figure35. The curve of color density (saturation) based on pixel in right direction (horizontal axis show pixel and vertical axis show saturation)

Figure36. The curve for the variation of concentration based on height in Geostudio 2012

Figure37. The comparison of concentration curve in Geostudio and image analysis in soil with 40% density in 5s

Table11. The results obtained from comparison of concentration curve in Geostudio and image analysis in soil with 40% density s

%average error from prediction of the concentration by image analysis	Rate of concentration decrease in depth(image analysis)	Rate of concentration decrease in depth(Geostudio 2012)	Time

Figures 37 to 40 show the concentration curve obtained from image analysis and Geostudio2012 for sandy soils with a relative density of 40%, and the results of the comparison are presented in Table 11.

Due to the fact that within 150 seconds the pollutant penetrates underground water, for its variations in concentration related to depth, two curves is plotted. A curve looks at changes in concentration to the surface of the groundwater level, and the other examines the changes in concentration after entering the groundwater.

Figures 41-43 show curve of the image analysis method and Geostudio2012 for sandy soils with a relative density of 100%, and the results of the comparison are presented in Table 12.

As shown in curves, the concentration curves obtained from image analysis and Geostudio 2012 have the same rate of decline and have ability to estimate the concentration of pollutants in the soil with negligible percent error. By increasing soil density, the difference between the curves obtained from image analysis and software decreases. By entering the pollutant into the groundwater due to the difference in the background color of the photo in the soil saturation region, the intensity of the pollutant become more and image analysis is not able to predict well the concentration. Therefore, it is suggested to examine the changes in concentration to the boundary between the pollutant and the groundwater level.

7. Conclusion

1. The trend and pattern of pollutant emissions in soil depths are strongly influenced by soil and fluid properties such as permeability, porosity ratio, volumetric water content, relative density of soils, and relative density of pollutants, longitudinal and transverse dispersion coefficients, and diffusion coefficient for pollutants.

2. In coarse-grained soils, the time of pollutant penetration into the soil and reaching it to the groundwater level, decreases with decreasing relative density of soil. In other words, by decreasing the relative density of soil, the porosity and soil permeability ratio increased and, as a result, the penetration rate of the pollutant increases.

3. In coarse-grained soils, the longitudinal expansion of the soil decreases with decreasing relative density of the soil.

4. In coarse-grained sandy soils at a specific density, by decreasing the soil water content, the penetration rate of the pollutant into the soil increases and its longitudinal expansion decreases.

5. In the coarse-grained sandy soils, by increasing the relative density of the soil, the level of capillary increases. In other words, by increasing the relative density of the soil, the cavity becomes smaller, and water as a wetting fluid is placed in the capillary paths and smaller soil cavities, so the level of capillary increases.

6. In the tested sandy soil, pollutant penetration into the soil occurs at a lower rate. This is due to the increase in soil depth because of the weight of the upper layers and approaching to the groundwater level.

7. The image analysis method in unsaturated soils, before the pollutant reaching to the groundwater level, is able to accurately estimate the concentration of pollutants at different depths.

8. By increasing soil density, the difference between the curves obtained from image analysis and software decreases.