Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (42) No. (2) April, 2020

THE EFFECT OF TRANSIENT GROUNDWATER FLOW ON CONTAMINANT DISPERSION IN POROUS MEDIA

Omar Ibn Alkhattab Mohamed Taha Abo- Alwafa [1]
Walid Alsayed (2),Rani Fouad(3),Anas El-Molla [4]
[1]Demonstrator, Irrigation and Hydraulics Depart., Faculty of Engineering, Al-Azhar University, Egypt.
[2] Ass. Prof. of Irrigation and Hydraulics. Al-Azhar University (Cairo)
[3] Dr. of Irrigation and Hydraulics. Al-Azhar University (Cairo)
[4] Prof. of Irrigation and Hydraulics, Faculty of Engineering. Al-Azhar University.

ملخص:
التنبؤ بانتشار الملوثات في باطن الأرض يعتمد على الفهم الدقيق لحركة هذه الملوثات خلال سريان المياه الجوفية في باطن التربة.
ومن المعروف أن التقدير الخاطئ لمسار حركة هذه الملوثات في باطن الأرض قد يؤدى إلى تقييم خاطئ لحجم الأخطار الناتجة عن هذه الملوثات.
في الأبحاث السابقة تم التوصل إلي أن انتشار الملوثات يتأثر بشكل أساسى بنفاذية التربة التي يتحرك خلالها.
وفي هذا البحث تم دراسة أهم المتغيرات المختلفة التي تؤثر بطريقة مباشرة علي انتشار الملوثات أثناء حركة المياه الجوفية في باطن الأر ض, حيت تم تصميم نموذج معملي لدراسة تأثير مختلف المتغيرات علي السريان المتغير أثناء حركة المياه الجوفية على انتشار الملوثات في التربة.
يتكون النموذج من أربعة خزانات كما هو موضح بالصورة المرفقة بالبحث.
لعمل محاكاة للأبار على أعماق ومسافات مختلفة- لمتابعة سلوك سريان وانتشار المياه الجوفية- تم إحضار أربع مواسير بقطر 3سم وطول 70سم, وتم تثقيبها بقطر 3مم للثقب الواحد مع إحاطة كل منها بمرشح للسماح بمرور الماء ومنع تسرب الرمل إلى البئر. تم تثبيت المواسير الأربعة رأسيا في التربة بكامل العمق على مسافات 20سم بطول الخزان الرئيسي وفي منتصف العرض لتكون مجالا يسمح بمرور ماسورة البئر حسب الأعماق والمسافات المختلفة أثناء عمل التجارب.أما ماسورة البئر فهى بقطر 0.5بوصة تم تثقيبها بنسبة معينة حسب معادلة موضحة فيما بعد.
كما تم عمل أربع بيزومترات بطول الخزان مناظرة لمواقع الأبار لملاحظة خط الميل الهيدروليكي أثناء السريان.
هذا وقد تم تثبيت حنفية تصريف عند نهاية طول الخزان على خط الأبار مع وضع كمية مناسبة من الزلط المتدرج أمامها كمرشح لمنع الإنسداد.
أما بالنسبة للمتغيرات المعملية فقد تم إجراء التجارب لدراسة خطوط الرشح وحركة السريان للمياه الجوفية بشحن الأبار تحت ضاغط ثابت على أعماق اختراق مختلفة لنفس البئر وكذلك مسافات مختلفة لنفس عمق الإختراق ورسم خط الرشح المناظر لكل تجربة وذلك لدراسة:
_ تأثير نفس العمق عند نقط الشحن المختلفة و تأثير اختلاف عمق الشحن لنفس موضع البئر و رسم تجميعي لمختلف نقاط الشحن.

ABSTRACT

Prediction of contaminants dispersion inside the ground depends on the accurate understanding for these contaminants movement in groundwater. Wrong estimation for this movement path may lead to wrong evaluation for contaminant dangers.
In previous researches it has been proven that the spreading of contaminants depends mainly on the permeability of soil. This research has studied the most important variables that affect directly on contaminant dispersion during the groundwater movement inside the ground. The experimental model was designed and setup to study the effect of different parameters on transient flow during the groundwater movement on contaminant dispersion in the soil.

Key words: Groundwater flow, Contamination dispersion, Transient flow.

1. INTRODUCTION

Groundwater is a valuable natural resource. Its contamination is one of the most typical hydro-geological and environmental problems. In many parts of the world, groundwater resources are under increasing threat from growing demands, wasteful use and contamination. The fate and transport of solute in soils and groundwater has long been a focus of experimental and theoretical research in subsurface hydrology. Solute transport in the soil and the groundwater is affected by a large number of physical, chemical and microbial processes; and the properties of the media. In many practical situations, one needs to predict the time behavior of a contaminated groundwater layer. Most of the groundwater contaminants are reactive in nature and they infiltrate through the vadoze zone, reach the water-table; and continue to migrate in the direction of groundwater flow.

Therefore, it is essential to understand the transport process of contaminants through the subsurface porous media. Several mathematical models have been developed in view of this based on the several numerical studies. Besides, there have been some experimental investigations conducted for understanding the behaviour of contaminant transport through different types of media. In this research the experimental investigation was carried out in the faculty of engineering, AL-Azhar University for modeling of contaminant transport through porous media.

Several researchers are carrying out experimental investigations through laboratory and field studies. Many of them are working on the analytical and numerical studies to simulate the movement of contaminants in soil and groundwater of the contaminant transport. Barone et al. (1992) described a laboratory diffusion-test for estimation of the diffusion coefficient (D) and the adsorption coefficient (K_d) for several volatile organic species in a clayey soil [1,2]. Awadallah and Abu-Ghararah (1997) demonstrated the horizontal contaminant transport through unsaturated sandy clay soil both analytically and experimentally. The predicted solute concentration profile was compared with that obtained experimentally and a fair agreement was observed in the analytical and experimental solutions [3]. Likos and Lu (2004) described a new lecture module and laboratory experiment for demonstrating chemical transport phenomena in soils. Simple coloured dye was used to simulate a contaminant in a flowing soil-water system, thus precluding the requirement for expensive and complex analytical equipment involved in traditional chemical transport testing and creating a highly visually oriented learning environment [1,4]. Ballarini et al. (2012) described the detailed numerical simulation of highly controlled laboratory experiments using uranine, bromide and oxygen depleted water as conservative tracers for the quantification of transverse mixing in porous media [5]. From the results, an improved experimental set-up as well as a numerical evaluation procedure could be developed, which allow for a precise and reliable determination of dispersivities [1]. Lake and Rowe (2005) examined the performance of a geomembrane/compacted clay composite liner of 2.9 m thick, at the end of its 14 year operational lifespan of a landfill located in Ontario, Canada. This case study highlighted the importance of the compacted clay liner as part of the composite liner system in acting as a diffusion barrier during the lifetime of the lagoon as well as using relatively non-conservative contaminants such as chloride and sodium to estimate geomembrane failure times [6]. Vrankar et al. (2004, 2005) presented the approach for modelling the radionuclide migration through the geosphere using Kansa’s method with geostatistics. It may be noted that for solving advection-dispersion equation, radial basis function method is an appropriate alternative to the traditional method like finite difference method [7,8]. Mategaonkar and Eldho (2011) have developed Meshfree models for isotropic cases only and the same were applied for hypothetical problem and further on a field problem to compute head distribution. The PCM models which are based on radial basis function were compared with FEM simulations while that of field problems are compared with boundary element based model results [9]. The recharge wells are considered very important sources for water storage in layer soil [1]. Through this operation, recharge wells will be clogged due to many different sources; chemical, physical and biochemical sources. All suspended solids have a big effect on a physical clogging well [9]. Ahmed Ragab. et al, (2018) performed experiments in the hydraulic laboratory of the Faculty of Engineering, Al-Azhar University. The model consists of three tanks with the same dimensions: 0.52 m diameter, 0.85 m height. Water head was 1.20 m from perforation and changed to 1.35 m and 1.50 m after mixing different concentrations of all suspended solids. Measurements were undertaken and presented on tables and figures. The results were analyzed and discussed from which it was clear that the well clogging, due to total suspended solids, depends on two parameters: the flow rate which is affected by the water head and the concentration of all suspended solids. The efficiency of the well changed from 20% to 30% due to a change in the water head in sandy soil and the concentration of all suspended solids affects the efficiency by 70 % to 80%. Based on these results, it was found that recharging in sandy gravel soil is better than recharging in sandy soil.

Moreover, mathematic relations were established to relate all the parameters. These relations might enable engineers to calculate all the clear time to clog the well in different soils, to know the real value of decreasing the efficiency due to recharge in different water heads and different total suspended solids' concentrations [10].

As mentioned above, the current study includes experimental investigation of the effect of transient flow on contaminant dispersion of groundwater in porous media.

2-THEORITICAL APPROACH

Groundwater flow is divided into unsaturated and saturated flows. The groundwater system is an open system, with water entering and leaving the system at its boundaries. In addition, water may also be artificially removed from or added to the system through wells. The quantity of water stored in the system changes with time according to the rate by which water enters or leaves the system across the boundaries and is removed or added through wells. The partial differential equations that govern groundwater flow are obtained by first: applying the law of mass conservation to a representative elemental volume which results in the continuity equation, and second: by using Darcy's law to express the motion of the flowing water.

3-EXPERIMENTAL WORK

3-1 Overview

In this paper we discuss the description of the model, wells and the sample of the soil used in the present study.

In addition, measurement parameters are presented as well.

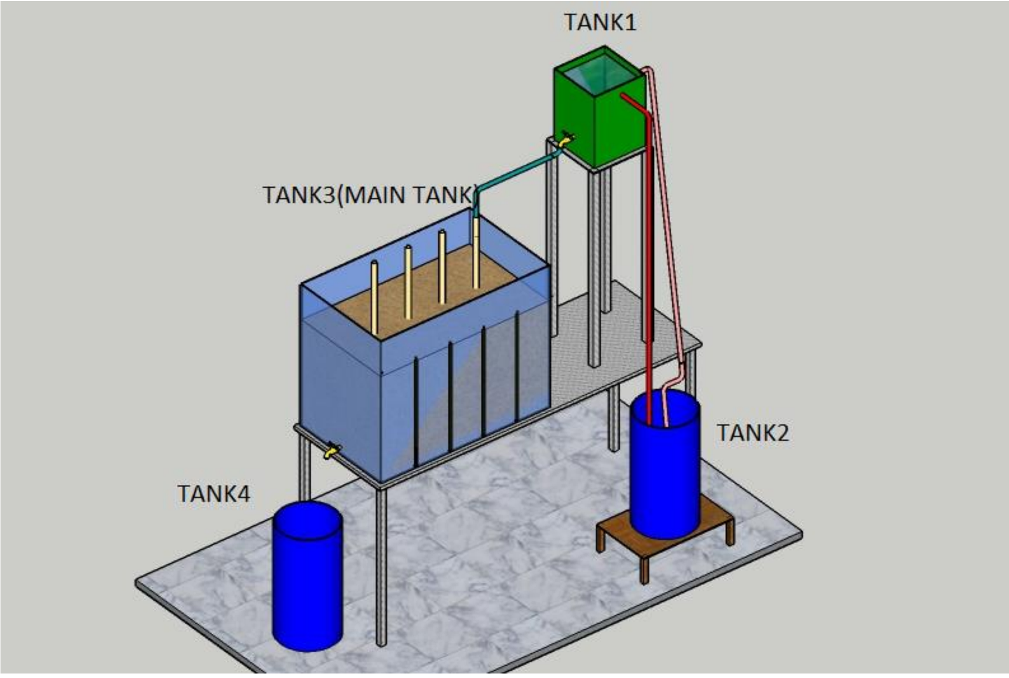

Figure 1: The experimental model of groundwater flow and dispersion

3-2 Model

The experimental investigation was carried out using four tanks.

(Tank1) is a glass tank with dimensions (30cm*30cm) square base and (H) 40cm in height.

This tank recharges wells in the main tank under constant head. At this head, there is a pipe to let excess water exit from water level at the same head.

(Tank2) which is called the feeding tank, is a cylindrical tank with dimensions (D) 33cm in diameter,(H) 65cm in height. The function of this tank is to keep the water surface in (Tank1) at constant level through all runs.

(Tank3) is the main tank because it consists of the type of soil which is our concern in this study. In addition, it consists of wells which receive the water from (Tank1) and recharge it in (Tank3) in the soil.

The main tank is a cast acrylic box with dimensions; (100cm in length, 60cm in width and 80cm in height).

(Tank4) which is called the out-flow tank, has the same dimension as (Tank2). This tank receives the flow out rate from the drain faucet in the main tank as shown in Figure (1).

There is a constant head pipe which is connected from (Tank2) to (Tank1) through a pump with total head 2.5m to take the water from (Tank2) through the constant head pipe to (Tank1) to keep the surface of water level stable.

3-3 Wells

Four perforated pipes with (D) 3cm diameter, (L) 70cm length were placed (fully penetrated) in mid-width of the main tank, in the soil and on the distances of 20cm along the length.

These pipes enable the well to penetrate the soil according to different depths and distances during the experiment runs. At each well, there are piezometers to observe the hydraulic gradient line.

The well with (Dw) 1.25cm (0.5 inch) diameter, (Lw) 80cm length of well was , in the soil as explained in figure (1).
This well has perforated circular openings (D_p) 3mm diameter.

Total side area of well * % perforation = Total area of perforation

Π D L *0.20 = Ns* As

Were;
Perforation percentage = 20% and $A_s = \pi Dp^2 \div 4$

3.14*1.25*60*.20 =Ns*0.07

Ns =672hole

For 20 cm height; 672÷3 =224 hole
For one vertical row; 224÷8 = 28 hole
The distance between two holes; 20÷28 =0.7 cm from C.L to C.L.

3-4 Sample of soil type

The soil sample which we use is sandy soil. Sieve analysis was applied on the sample to know the granular gradient for soil.
Sieve analysis indicated that it is an ideal sample.
Sand was sieved out on (4, 10) screen to separate grained gravel and obtain graded sand.
After that, we washed sand to purify it.
For drying it, sand was exposed to the sun's rays for a week.
After drying, I placed sand and compacted it in (Tank3) with 60cm in depth and a filter of particles was put in front of the out let of flow rate to prevent any settlement in soil layer and prevent the soil failure or clogging.

3-5 Experimental Study and Plan

A total of twelve experiments were conducted in the faculty of engineering. The following steps were carried out experimentally to draw flow lines for different depths and distances of wells.
1- Open the pump to recharge water in tank1 at constant head.
2-Open the faucet of (Tank1) to feed the well placed at defined position.
3-Open the out let faucet to receive the flow out rate from the well.
4-Observe piezometers and wait for stability of levels.
5- Draw the seepage line for this run.
6- Repeat all previous steps for different locations of wells.
7- Experimental runs shown in Appendix (A)

4. Measurement Parameters

The experiments were carried out for studying groundwater flow and seepage lines. Wells were recharged under constant head at different penetration depths for the same well and different locations for the same penetration depth. We draw the seepage line for each run at the same time.
Measurement parameters to be researched are;
- Effect of the same penetration depth at different recharge points.
- Effect of the difference of recharge depths for the same location.
- The accumulative charts for all recharge positions.

5. Results and Analysis

The following accumulative charts have been carried out for studying the effect of difference between recharge depths and positions on groundwater flow and dispersion.

After studying (I accumulative curves) in figure (4), it is noticed that;
- A and B curves intersect at point (0.65, 0.7).
- C curve intersect with (A'B) curves at (0.55,0.65).
- D curve intersect with previous curves at (0.2,0.55).

After studying (II accumulative chart), it can be seen that as in figure (3);
- Curves height range is less than (III curves) from 0.5 to 0.7 .
- The intersection point of curves (A;B;C) is (0.6'0.7).

After studying (III accumulative chart) as seen in figure (2),
We can notice that;
-Position AIII; We observe that the seepage line slopes down ward
To the drain until it ends at the middle of height.
-Position BIII; at well B the curve level starts at (0.7) of the total height. Then, it begins to slope gradually towards the drain.
- Curves (A' B) intersect at point (0.2'0.62).
-Curves (C' D) separate at point (0.4'0.6).

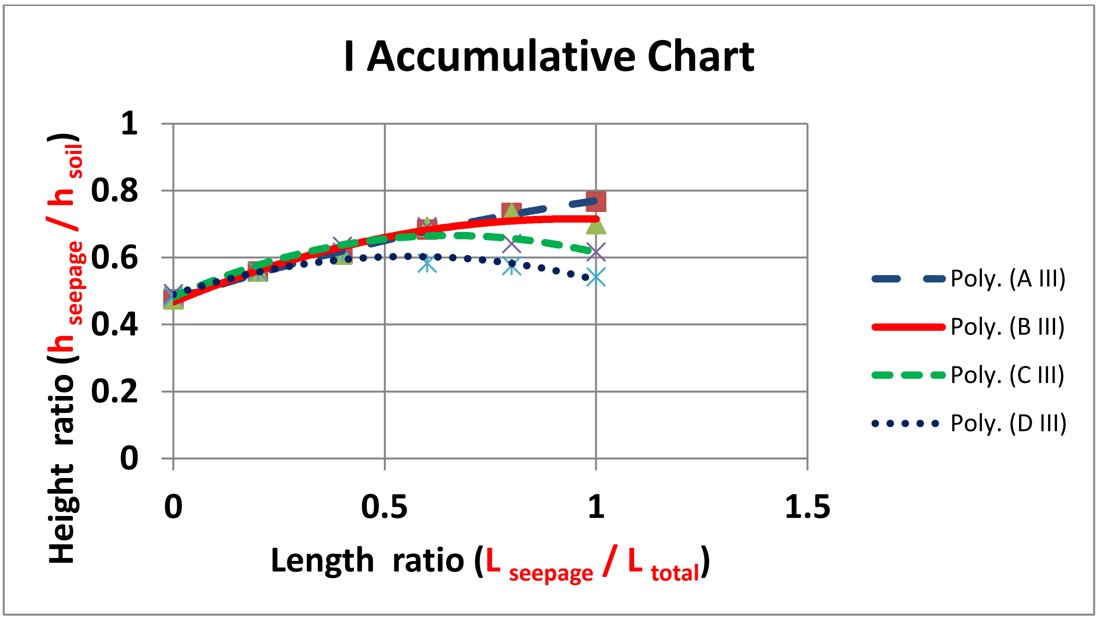

Figure (2) : Accumulative chart (I)

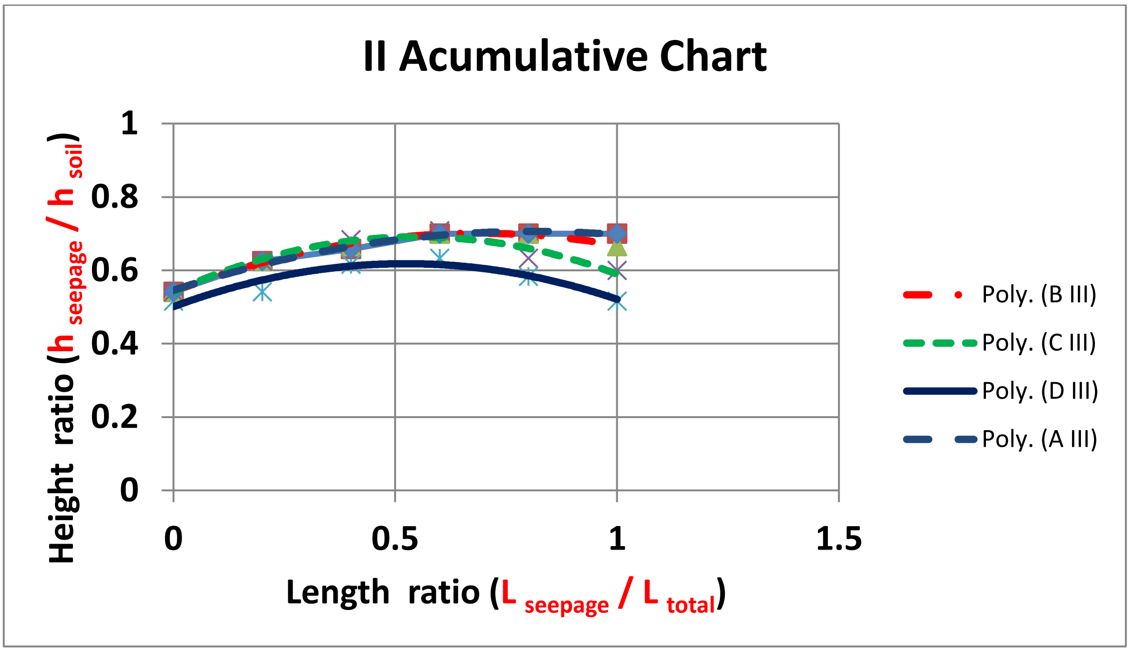

Figure (2) : Accumulative chart (II)

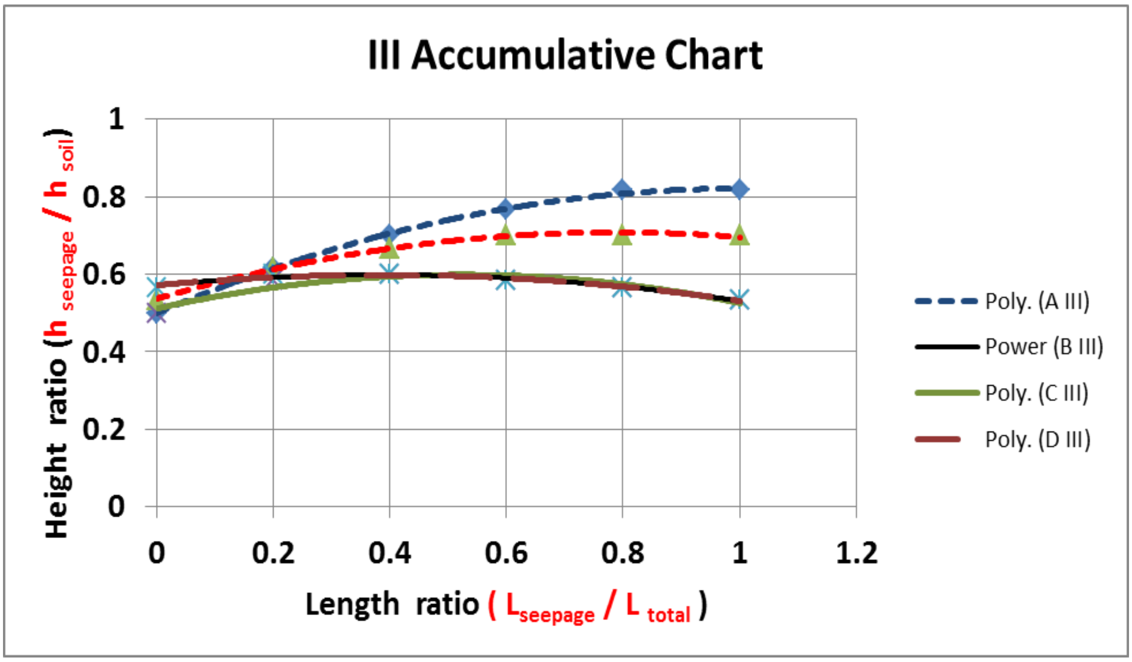

Figure (2): Accumulative chart (III)

6. CONCLUSION AND RECOMMENDATIONS

The recharge wells are considered very important sources for water storage in layer soil. The current study was performed experimentally in the hydraulic laboratory of the Faculty of Engineering, Al-Azhar University. Measurements and results were taken, analyzed and discussed from which it was clear that;

1- The water dispersion or the seepage lines depends mainly on two parameters: recharge positions and well penetration depth.

2- The presented experimental results show that the contaminant dispersion behavior is very close to the field results of previous studies.

3- It can be concluded that the penetration depth of well affects mainly on the ground water flow.

4-Moreover, it is observed that the perforation ratio has an impact on the rate of dispersion although it was not taken as an effective parameter of the case study. And consequently, it is recommended to take this parameter into consideration in further studies.

5-It is recommended to take into consideration the effect of wells interference in further studies.

6-It is recommended to carry out the experiment with different porous media

Photo (1);The experimental model

References:

[1] S.B. Patil, and H.S. Chore, (2014), "Contaminant transport through porous media: An overview of experimental and numerical studies," Advances in Environmental Research, vol. 3, No. 1 45-69. DOI: http://dx.doi.org/10.12989/aer.2014.3.1.045

[2] Barone, F.S., Rowe, R.K. and Quigley, R.M. (1992), "A laboratory estimation of diffusion and adsorption coefficients for several volatile organics in a natural clayey soil", J. Contam. Hydrol., 10(3), 225-250

[3] Awadallah, S.E. and Abu-Ghararah, Z.H. (1997), "Contaminant transport through initially dry soil", Water Air Soil Pollut., 100(2), 107-118.

[4] Likos, W. and Lu, N. (2004), "Integrated lecture and laboratory modules for contaminant transport studies in Undergraduate geotechnical engineering", J. Prof. Issues Eng. Educ. Pract, 130(1),19-25.

[5] Ballarini, E., Bauer S., Eberhardt, C. and Beyer, C. (2012), "Evaluation of transverse dispersion effects in tank experiments by numerical modeling: Parameter estimation, sensitivity analysis and revision of experimental design", J. Contam. Hydrol., 134(6), 22-36.

[6] Lake, C.B. and Rowe, R.K. (2005), "The 14-year performance of a compacted clay liner used as part of a composite liner system for a leachate lagoon", Geotech. Geol. Eng., 23(6), 657-678.

[7] Vrankar, V., Turk, G. and Runovc, F. (2004), "Combining the radial basis function Eulerian and Lagrangianschemes with geostatistics for modelling of radionuclide migration through the geosphere", Comp.Math. With Appl., 48(10), 1517-1529.

[8] Vrankar, V., Turk, G. and Runovc, F. (2005), "A comparison of the effectiveness of using the meshless method and the finite difference method in geostatistical analysis of transport modelling", Int. J. Comput. Meth., 2(2), 149-166.

[9] Mategaonkar, M. and Eldho, T.I (2011), "Simulation of groundwater flow in unconfined aquifer using Meshfree point collocation method", *Eng. Anal. Bound. Elem.*, **35**(4), 700-707.

[10] Ahmed Ragab, Anas M. El-Molla, Walid Alsayed, Mostafa Ali, Rani Fouad (2018), "Effect Of Flow Rate And Suspended Solids On Clogging Of Recharge Wells In Different Soil Types", MSc, Al-Azhar University.