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Contaminant transport through the soil: An overview of experimental and numerical studies

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ملخص:

المياه الجوفية مصدرا رئيسيا لإمدادات المياه على مر العصور. وهي أيضا مصدر مهم في قطاع الزراعة والصناعة. في أجزاء كثيرة من العالم ، تتعرض موارد المياه الجوفية لخطر متزايد من الطلب المتزايد والاستخدام المهدر والتلوث. هناك حاجة إلى ممارسات تخطيط وإدارة جيدة لمواجهة هذا التحدي. مفتاح إدارة المياه الجوفية هو القدرة على نمذجة حركة السوائل والملوثات في البيئة تحت السطحية. من الواضح أن أنشطة مصدر الملوثات لا يمكن القضاء عليها تمامًا ، وربما ستظل المسطحات المائية لدينا بمثابة مستقبلات لكميات هائلة من النفايات. في مثل هذا السيناريو ، يجب أن يكون هدف جهود حماية جودة المياه بالضرورة هو التحكم في هذه المصادر وإدارتها للتأكد من أن الملوثات التي تم إطلاقها سيتم تخفيفها بشكل كافٍ داخل المنطقة ذات الاهتمام وعدم إضعاف جودة المياه في نقاط الانسحاب. من أجل فهم سلوك نقل الملوثات من خلال أنواع مختلفة من الوسائط ، يجري العديد من الباحثين تحقيقات تجريبية من خلال الدراسات المختبرية والميدانية. يعمل الكثير منهم على الدراسات التحليلية والعددية لمحاكاة حركة الملوثات في التربة والمياه الجوفية لنقل الملوثات. مع ظهور أجهزة الكمبيوتر عالية الطاقة على وجه الخصوص ، اكتسبت النمذجة العددية شعبية وهي في الواقع ذات أهمية خاصة في هذا الصدد. تقدم هذه الورقة حالة نقل الملوثات ومراجعات الأعمال البحثية المتحالفة المنفذة من خلال البحث التجريبي أو باستخدام الحل التحليلي والطريقة العددية. تتضمن المراجعة التحقيق فيما يتعلق بكل من الوسائط المشبعة وغير المشبعة والمسامية.

Abstract

The groundwater has been a major source of water supply through out the ages. The groundwater is also an important source in the agriculture and industrial sector. In many parts of the world, groundwater resources are under increasing threat from growing demands, wasteful use and contamination. A good planning and management practices are needed to face this challenge. A key to the management of groundwater is the ability to model the movement of fluids and contaminants in the subsurface environment. It is obvious that the contaminant source activities cannot be completely eliminated and perhaps our water bodies will continue to serve as receptors of vast quantities of waste. In such a scenario, the goal of water quality protection efforts must necessarily be the control and management of these sources to ensure that released pollutants will be sufficiently attenuated within the region of interest and the quality of water at points of withdrawal is not impaired. In order to understand the behaviour of contaminant transport through different types of 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. With the advent of high power computers especially, a numerical modelling has gained popularity and is indeed of particular relevance in this regard. This paper provides the state of the art of contaminant transport and reviews the allied research works carried out through experimental investigation or using the analytical solution and numerical method. The review involves the investigation in respect of both, saturated and unsaturated, porous media.

Keywords: *contaminant transport, experimental investigation, analytical studies, numerical modelling.*

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. So the focus in this paper on the studies related to contamination generally to control contaminant transport and its distribution through porous medium and understand methods used to solve contamination transport through the soil. 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 behavior of contaminant transport through different types of media. These methods to prevent, stop and treat the groundwater contaminations.

1.1 CAUSES OF GROUNDWATER CONTAMINATION

A groundwater contaminant is defined by most regulatory agencies as any physical, chemical, biological or radiological substance or matter in groundwater. The contamination can occur by natural processes, agricultural operations urban run offs, waste disposal practices, spills and leaks etc.The natural process includes leaching of chemical deposits which further results in increased concentrations of chlorides, sulphates, nitrates and other inorganic chemicals, Chopda and Malek [13]. Besides leaching, the other most significant source is runoff. The water carries metals, pesticides, microorganisms and other organic chemicals. The third general source of groundwater contamination is waste disposal. It includes disposal of liquid and solid wastes. The liquid wastes include disposals from septic tanks, cesspools, sewage effluent, sludge in regard with the industrial wastes, surface impoundments and injection wells are probably the largest contributors to groundwater contamination.

2. Review of literature

Some of the published works on the various studies in regard with the contaminant transport through porous media are reviewed in this section.

2.1 Numerical Studies

Numerical modelling of pollutant migration in porous media has recently received a great deal of attention due to an increased interest in the preservation of the quality of the environment and particularly the protection of groundwater from various pollutants. Numerical models are able to account for the complexity of the subsurface and accommodate complicated boundary conditions. The numerical techniques are utilized employing: The finite difference methods (FDM), the finite element method (FEM) and boundary element methods (BEM).

Patil and Chore. [41] provided An overview of experimental and numerical studies in respect of Contaminant transport through porous media .they provided the state of the art of contaminant transport and reviews the allied research works carried out through experimental investigation or using the analytical solution and numerical method. The review involves the investigation in respect of both, saturated and unsaturated, porous media.

Liu and Hu [33] investigated the transport of organic acids (commonly found in landfill leachate) through a partially saturated composite liner system beneath a landfill.by using A one-dimensional model. The influence of water content distribution on aqueous-phase diffusion process was studied. Composite liner system was used .Quirk model was employed to describe the non-linear relationship between volumetric

water content and diffusion coefficient. Three cases were analyzed and compared, i.e., totally saturated condition, unsaturated condition without considering unsaturated diffusion model, and unsaturated condition considering unsaturated diffusion model. The numerical results show that:

- The unsaturated sand attenuation layer could serve as excellent diffusion barrier to organic contaminant due to its low water retention capacity.
- The dependence of diffusion coefficient on volumetric water content is sufficiently considered.
- The contaminant flux decreases significantly in all the three kinds of attenuation layer.
- Unsaturated diffusion model capturing the relationship between water content and diffusion coefficient enabled a more reasonable prediction of contaminant transport and distribution in soils.

Tuncan [51] determined the groundwater and soil pollution within and around the landfill of Eskisehir, Turkey. Mud, leachate and groundwater samples were collected seasonally a year from near Eskisehir landfill-site to investigate the possible impact of leachate which affects soil and groundwater quality. Concentrations of various heavy metals were determined in mud, leachate and groundwater samples. The modelling of the contaminant transportation was carried out by using a multiflow computer programme which simulates the distribution of heavy metal concentrations. The results show that:

- The contaminant concentrations were determined at any time interval according to distance.
- The heavy metal contamination in groundwater does not affect the wells found at far points from the source in a short time, e.g. 10, 20 and 30 days according to the obtained experimental results.
- When the time intervals extended more than1 year, heavy metal concentrations decrease with distance but the concentration of the contamination increases when it gets closer to the pollution source.

2.2 Experimental Investigations

Experimental studies are the essential tools in the geo-environmental engineering for understanding the transport of adsorbed and non-adsorbed solutes through soil. Experiments can be used to obtain the properties necessary to model the movement of contaminant in porous media in a realistic situation. The experiments provide valuable insight about the porous medium, the behaviour of chemicals, and associated processes such as diffusion, dispersion, anion exchange and sorption during transport. The brief review of some of the significant experimental investigations reported in the past is given below.

Still and Nash [49] studied groundwater contamination due to pit latrines located in a sandy aquifer. They described local and international research in this field, and examines the justification of the 75 meter from water sources. The paper described field research which has been conducted in the maputaland area of kwazulu-natal, where there are large numbers of both pit latrines and shallow wells, and also described the observations of water quality in a range of well types spread throughout the area. They concluded that:

- A fine sandy soil is an effective filter medium and that pit latrines pose a negligible health risk in such an area, with the safe distance for water abstraction being more like 20 metres.
- Water quality in wells depends on well design and how the well is used.
- The paper shows that properly designed and maintained wells produce water of good quality.

Armanyous et al. [6] controled the contaminant transport through soil by using equal double sheet piles. They used experimental work by using physical sand box model in order to examine the effect of many variables such as depths of double sheet piles, distance between them and distance between contamination source and sheet piles. Design charts were presented for quantifying the effects of equal double sheet piles on the hydraulic control of the groundwater flow field. From the charts, the double sheet piles depth can be selected according to the needed condition.

2.3 CONTROL OF GROUNDWATER CONTAMINATION

The design of waste disposal facilities typically involves a barrier that separates the waste from the general groundwater system. The type of vertical barriers are slurry walls, sheet pile walls, frozen barriers, composite walls, grout barriers, vibrating beam cutoff barrier, horizontal Barriers and treatment walls, Pearlman [42]. Slurry wall is the most common type of subsurface wall and is considered baseline barrier Technology.it is a subsurface barrier made to redirect the flow of groundwater.it is very successful in controlling pollutants, contaminated ground water and landfill leachate migrating from waste sites. There are different materials, and combinations of materials, that can be used to construct slurry Cutoff walls including soil-bentonite, cement-bentonite, and plastic concrete, Pearlman [42]. Zhang and Qiu [53] investigated contaminant migration through the vertical barrier walls in a landfill. They used two-dimensional numerical model to analysis the problem. Advection, diffusive and adsorption processes were considered in the analysis. They considered the Influence of permeability and depth of the barrier wall on contaminant migration. They concluded that:

- If the bottom of the barrier wall is keyed into the aquitard and the hydraulic conductivity is no higher than 10-9 m/s, the breakthrough time will be long enough to enable stabilization of waste within the landfill.
- Pollution of the surroundings will be avoided and therefore, the barrier wall will satisfy the requirement for contaminant control.

Eltarabily and Negm [19] studied the behavior of nitrate transport through sand by using vertical wall of sheet pile as a barrier. The involved parameters are the penetration depth of protection wall, location of wall from the pollution source, and the head deference of the water level. The results show that: the best location and Depth of the vertical barrier are determined to minimize the Proportion of the reached contaminant to attain the maximum Possible protection of the drain's water. Basha et al. [8] studied the effect of vertical sheet piles on hydraulic control and contamination transport through the soil. They used numerical model to investigate the influence of installing a vertical sheet pile on the rate of contaminant transport. This model has many variables to analysis the numerical model such as depth of sheet pile, distance between contamination source and sheet pile, hydraulic conductivity of porous media, head difference. They used Experimental work by using sand box model to verify numerical model. Armanyous et al. [6] controlled the contaminant transport through soil by using equal double sheet piles. Design charts were presented for quantifying the effects of equal double sheet piles on the hydraulic control of the groundwater flow field. From

the charts, the double sheet piles depth can be selected according to the needed condition. Ali [4] showed the effect of middle sheet pile or cutoffs on the uplift pressure under the hydraulic structures by using finite difference method with a relaxation technique.

Anderson, and Mesa [5] investigated the effect of vertical barrier on the hydraulic control of contaminated groundwater. Abdoulhalik and Ahmed [2] used cutoff walls in controlling saltwater intrusion in stratified heterogeneous coastal aquifers. Smith et al. [48] used cutoff walls to prevent off-site migration of contaminated groundwater or soil gases to adjacent property and waterways.

3. Conclusions

- Several researchers conducted experimental investigations either in laboratory or in field besides carrying out the analytical studies and numerical modelling for understanding the behavior of contaminants in porous media and for predicting the future contamination level.
- The experimental studies are regarded as complimentary to the analytical and numerical studies.
- Various types of barriers were used to control contamination transport such as slurry walls, sheet pile walls, frozen barriers, composite walls, grout barriers, vibrating beam cutoff barrier, horizontal Barriers and treatment walls.

References

1. Abdoulhalik, A., & Ahmed, A. A., 2017. The effectiveness of cutoff walls to control saltwater intrusion in multi-layered coastal aquifers: Experimental and numerical study. Journal of Environmental Management, Vol.199, PP. 62–73.
2. Ali, W. S. M., 2011. The Effect of Middle Sheet Pile on the Uplift Pressure under Hydraulic Structures. European Journal of Scientific Research, Vol.65, No.3, pp. 350-359.
3. Anderson, E.I., & Mesa, E., 2006. The Effects of Vertical Barrier Walls on the Hydraulic Control of Contaminated Groundwater. Advances in Water Resources, Vol. 10, pp. 89-98, No. 29.
4. Armanyous, A.M., Ghoraba, S.M., Rashwan, I.M.H., & Dapaon, M.A., 2015. A Study on Control of Contaminant Transport through The Soil Using Equal Double Sheet Piles. Ain Shams Engineering Journal, Vol. 7, pp. 21-29.
5. Basha, A., Al-Nimr, Rashwan, I.M.H., & Gabr, A., 2012. Use of Sheet Piles to Control Contaminant Transport through the Soil. Journal of American Science, Vol. 6, pp.568-573, No. 8.
6. Chopda, M., Malek, A.M., 2018. Contamination of Groundwater Quality Due to Municipal Solid Waste Disposal – A GIS Based Study. International Research Journal of Engineering and Technology, Vol.5, PP 4836 – 4842.
7. Eltarabily, M., & Negm, A.M., 2015. Numerical Simulation of Fertilizers Movement in Sand and Controlling Transport Process Via Vertical Barriers. International Journal of Environmental Science and Development, Vol. 6, pp. 559-565, No. 8.
8. Liu, T., & Hu, L., 2014. Organic Acid Transport through A Partially Saturated Liner System beneath A Landfill. Geotextiles and Geomembranes, pp. 1- 9.

9. Patil, S.B., & Chore, H.S., 2014. Contaminant Transport through Porous Media: An Overview of Experimental and Numerical Studies. Advances in Environmental Research, Vol. 3, No. 1, pp. 45-69.
10. Pearlman, L., 1999. Subsurface Containment and Monitoring Systems: Barriers and Beyond", National Network of Environmental Management Studies Fellow, Vol.66.
11. Smith, D., Jowett, R., & Gamble, M., 1997. Sealable Joint Steel Sheet Piling for Ground Water Control and Remediation: Case Histories. The International Containment Technology Conference.
12. STILL, D.A., & NASH, S.R., 2002. Groundwater Contamination Due to Pit Latrines Located in A Sandy Aquifer A Case Study from Maputaland. Water Institute of Southern Africa, Biennial Conference, Durban.
13. Vidic, R. D., & Pohland, F. G., 2000. In Situ Groundwater Remediation Using Treatment Walls. Emerging Technologies in Hazardous Waste Management, pp.119-139.
14. Zhang, W.J., & Qiu, Q.W., 2010. Analysis on Contaminant Migration Through Vertical Barrier Walls in A Landfill in China. Environ Earth Sci, Vol. 6, pp. 847–852.