

# Mechanism of Transfer of a Pollutant in the Unsaturated Zone of an Industrial Site (Typical Case of the Paint Plant of City of SOUK AHRAS)

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## Abstract

The work discussed here is part of a comprehensive study to develop tools for characterization and modeling of pollutant flows transported by water flowing in the unsaturated zone of an aquifer (quantitative approach). In our study, we present a practical model for calculation of transfer of pollutants emitted by a source of pollution in our case represented by a production plant paintings located in the city of SOUK AHRA

**Keywords:** Mechanism of transfer, Model, Modeling, Contaminated aquifer, Environment.

## 1. Introduction

Since the construction in the late seventies, a factory producing paint in the city of SOUK AHRAS, no scientific study has been made to verify the risk of groundwater pollution in the basement of this factory. On using the laws of physical behavior and mathematical model, we will try to understand both the mechanisms of transfer of water and solutes in a unsaturated soil with a flow rate bi-and three-dimensional and in the presence of a body of water drained, and assess the potential risk of pollution [3],[6],[7],[8],[10]. To this end, a series of sampling water and soil was conducted over a period which lasts for twelve months from 11/2007 to 11/2008, to be analyzed in the laboratory, for the determination of physical characteristics of soil and groundwater quality.

### 1.1. Equation of Continuity

The Darcy's law indicates that the flow of the liquid through a porous medium, is in the direction of the driving force: the hydraulic gradient acting on the liquid. The flow also depends on a fundamental characteristic of soil: permeability, the present trend tends to describe *hydraulic conductivity*. At the macroscopic scale, Darcy's law can be generalized to the variable saturated media, assuming the hydraulic conductivity is a function of potential pressure.

$$\vec{q} = -\overline{K}(\Psi) \cdot \vec{\nabla} \Phi \quad (1)$$

The equation of Richards (1931) describes the transfer of water in the porous medium variable saturated. It derives from the combination of the generalized law of Darcy (Eq.1) with the continuity equation:

$$\frac{\partial \theta}{\partial t} = -\vec{\nabla} \cdot \vec{q} \quad (2)$$

The generalized Darcy law, developed in conjunction with the equation of conservation of mass, assuming an incompressible fluid, of density and of dynamic viscosity constant, gives the equation described by Richards (1931) [4]:

$$\frac{\partial \theta}{\partial t} = \text{div} \left[ -\overline{K}(\Psi) \cdot \vec{\text{grad}}(\Phi(x, y, z, t)) \right] \quad (3)$$

The Richards equation is a nonlinear equation whose resolution generally requires digital means [9]. The resolution of the equation is very sensitive to the determination of the relations describing the hydrodynamic parameters, especially near saturation [10].

### 1.2. The Convection

Convection is the shift elements in solution in the movement of fluid. The solute is transported by the general movement of water at a speed ( $q$ ) defined by Darcy's law. The principle of conservation of mass can write:

$$-\vec{\nabla} \cdot (C \cdot \vec{q}) = \frac{\partial}{\partial t} (C \cdot \theta) \quad (4)$$

### 1.3. The Molecular Diffusion

Physico-chemical phenomenon that tends to make uniform the spatial distribution of solute concentration, up to a uniform concentration by diffusion into the less concentrated (in a hypothetical case where the fluid is at rest).

Its influence becomes important only in cases of slow flow ( $<10^{-7} \text{ cm.h}^{-1}$ ). In this context, we can write the equation for the diffusivity [1]:

$$\frac{\partial}{\partial t} (\theta \cdot C) = \vec{\nabla} \cdot \left( \theta \cdot \overline{D} \cdot \vec{\nabla} (C) \right) \quad (5)$$

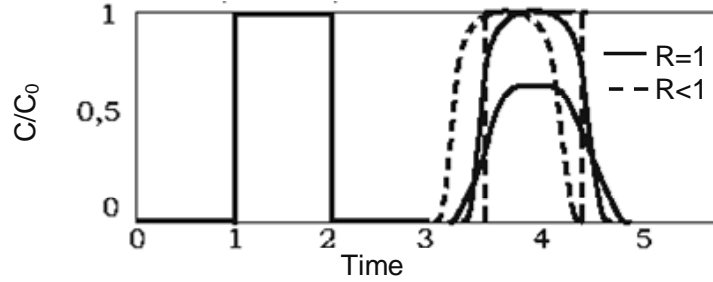
### 1.4. Equation of the Classical Convection Dispersion

If one considers that the total flow of fluid is composed of dispersive and convective flow, transport can be described by the classical equation of convection-dispersion:

$$R \frac{\partial \theta C}{\partial t} = \frac{\partial}{\partial x_i} \left( \theta \overline{D}_{ij} \frac{\partial C}{\partial x_j} \right) - \frac{\partial}{\partial x_i} (q_i C) + \frac{q_s}{\varepsilon} C_s \quad (6)$$

The Darcy velocity is determined by the resolution of the Richards equation. The delay factor ( $R$ ) only for reactive solutes, for non-reactive (tracer ideal), ( $R = 1$ ) (Fig. 1).

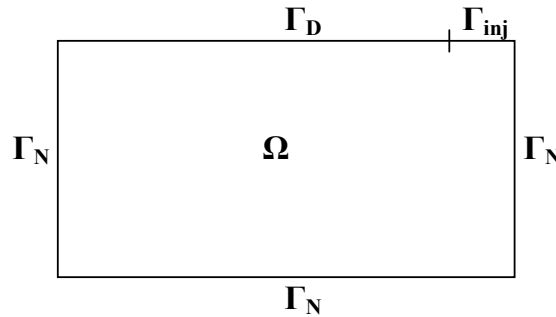
This variable is the rate of water divided by the speed of the tracer. For negatively charged ions such as chloride or bromide, ( $R < 1$ ) [11].

**Figure 1:** Effect of the delay factor.

Either ( $\Omega$ ) an open space bounded, we assume that the boundary ( $\partial\Omega$ ) is divided into three separate parts:

$$\partial\Omega = \Gamma_{inj} \cup \Gamma_N \cup \Gamma_D$$

The border ( $\Gamma_{inj}$ ) is the source of pollution, along which the flow is given by a function ( $g$ ). we impose more conditions of Neumann type is homogeneous on ( $\Gamma_N$ ) and Dirichelet homogeneous on ( $\Gamma_D$ ) (Fig.2) [2]

**Figure 2:** Field of work

At equilibrium the concentration  $c(x, t)$  is governed by the diffusion equation,

$$\left\{ \begin{array}{ll} R \frac{\partial \theta C}{\partial t} - \frac{\partial}{\partial x_i} \left( \overline{\theta D_{ij}} \frac{\partial C}{\partial x_j} \right) + \frac{\partial}{\partial x_i} (q_i C) - \frac{q_s}{\varepsilon} C_s = 0 & \text{in } \Omega \\ C(t=0, x) = C^0 = 0 & \text{in } \Omega \\ D \nabla C \cdot n = g & \text{on } \Gamma_{inj} \\ D \nabla C \cdot n = 0 & \text{on } \Gamma_N \\ C = 0 & \text{on } \Gamma_D \end{array} \right. \quad (7)$$

The variational formulation associated with the partial differential (Eq.6) is to determine

$$C(x, t) \in V := \{H^1(\Omega\Omega); = 0 \text{ on } \Gamma_D\}$$

Such as:

$$\int_{\Omega} \left( R \theta \frac{dC}{dt} - \overline{D_{ij}} \nabla C \cdot \nabla \theta + \nabla q C - \frac{q_s}{\varepsilon} C_s \right) dx = \int_{\Gamma_{inj}} g \theta ds \quad \text{for any } \theta \in V \quad (8)$$

For the numerical solution of the variational formula (Eq.8) the discretization of the time

derivative is written:  $\frac{dC}{dt} \approx \frac{C^n - C^{n-1}}{\Delta t}$

Thus, ( $C^n$ ) approximation of the concentration at the time ( $n\Delta t$ ) is a variational solution of the problem.

$$\int_{\Omega} \left( \frac{C^n(x) - C^{n-1}}{\Delta t} R\theta - \overline{D_{ij}} \nabla C^n \cdot \nabla \theta + \nabla q C^n - \frac{q_s}{\varepsilon} C_s \right) dx = \int_{\Gamma_{inj}} g \theta ds \quad (9)$$

For all  $(\theta \in V)$  this formulation is solved with a finite element approximation of Lagrange P1

## 2. Results (qualitative response of the model)

The purpose of this part is to test the effectiveness of our model for determining the state of concentration (C). The implementation of (Eq.8) and (Eq.9) was carried out under the code FreeFem++, Version 2.11 [5]. Out of approximately 02Ha that covers the installation of a plant for production of paints (source of contamination) located at the north end of town SOUK AHRAS in the north east of Algeria. A representative vertical profile of the site was modeled with the code FreeFem++[5], with this program we have simulated a possible infiltration of chemicals emitted by a surface unit, with the parameters:

**Table 1:** Characteristic of the source of pollution

<b>Speed of flow [M/d]</b>	<b>0.24 m/d</b>
The prompt injection mass [G]	1000.00 g
Degree of injection of source [G/d]	2.74 g/d
The factor of degradation [1/d]	1.00 1/d
The factor of delay [-]	1.00
Length of the source [M]	1.00m
Width of the source [M]	1.00m

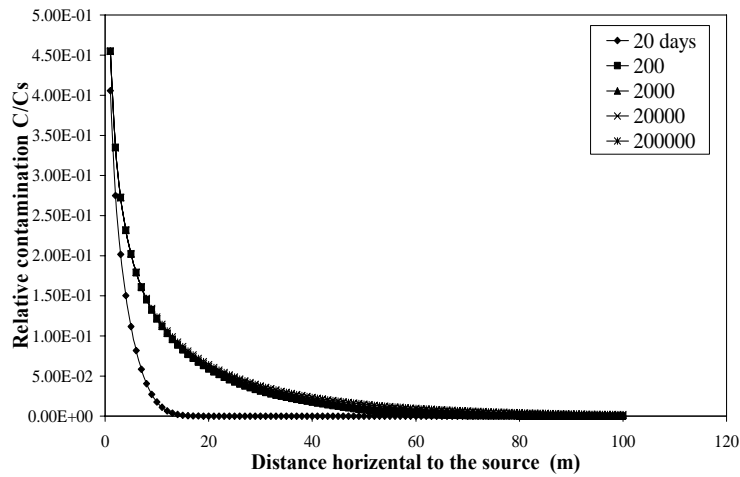
**Table 2:** Parameters of the simulation

	<b>Test 01</b>	<b>Test 02</b>	<b>Test 03</b>	<b>Test 04</b>	<b>Test 05</b>
Total distance [m]	100.00	100.00	100.00	25.00	5.00
Step of length [m]	1.00	1.00	1.00	1.00	1.00
The total time [d]	$2 \times 10^1 \div 2 \times 10^6$	$2 \times 10^1 \div 2 \times 10^6$	$2 \times 10^1 \div 2 \times 10^6$	$2 \times 10^6$	$2 \times 10^6$
Depth [m]	0.00	2.00	5.00	$0 \div 5 \div 10$	$0 \div 2 \div 10$
Thickness of aquifer [m]	10.00	10.00	10.00	10.00	10.00
Porosity effective [-]	0.25	0.25	0.25	0.25	0.25
The longitudinal dispersion [m]	2.00	2.00	2.00	2.00	2.00
The transverse dispersion [m]	0.20	0.20	0.20	0.20	0.20
Method of analyses:					
prompt contamination (1.00)	2.00	2.00	2.00	2.00	1.00
contamination continuous (2.00)					

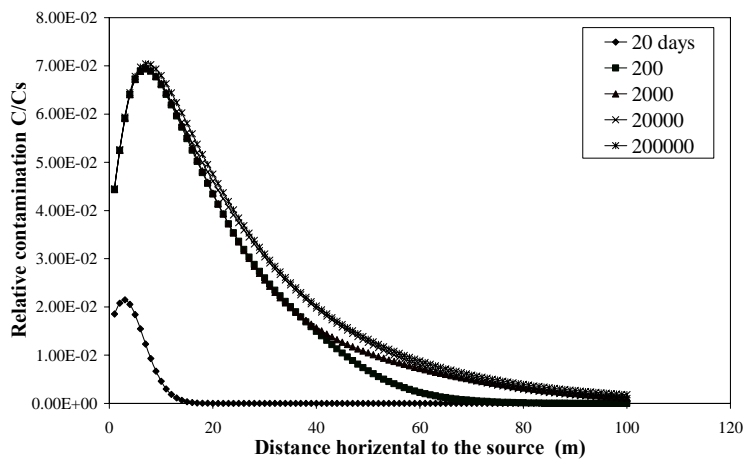
**Figure 3:** State of concentration at 200 days (Iso values).



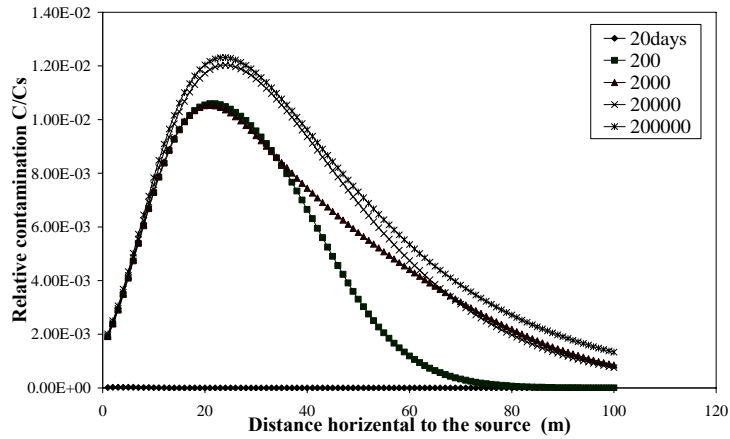
**Figure 4:** State of the contamination to the surface (contamination by continue injection). Test01



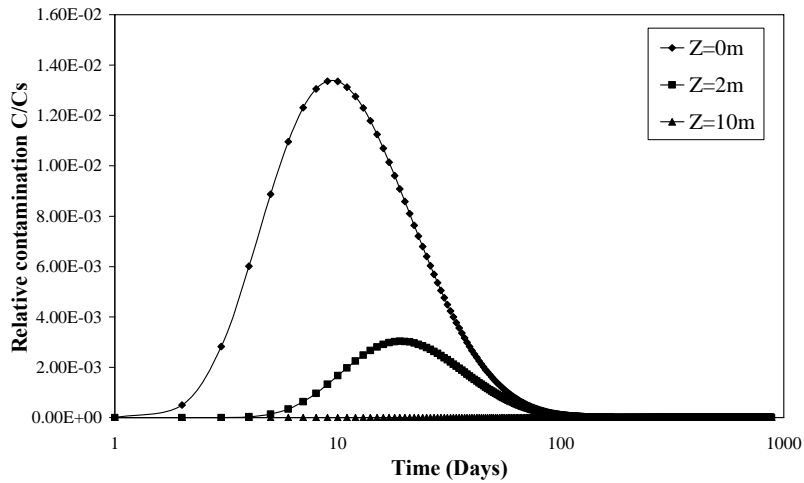
**Figure 5.** State of concentration at a depth of 02m (contamination by continue injection) Test02.



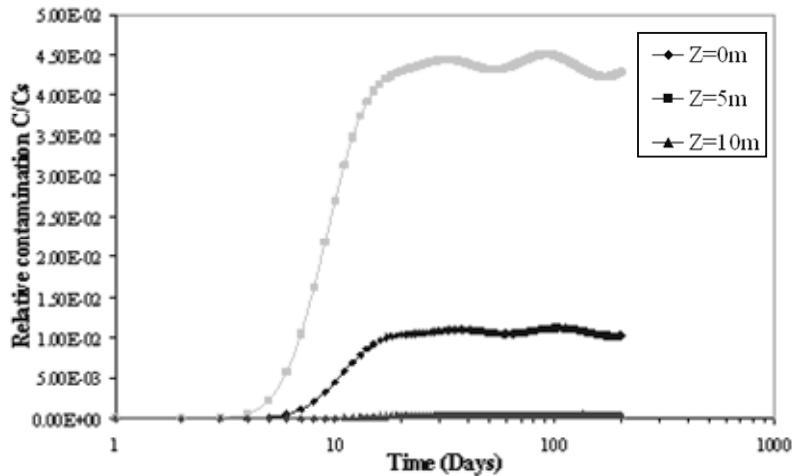
**Figure 6:** State of concentration at a depth of 05m (Contamination by continue injection).Test03



**Figure 7:** State of concentration at a position constant  $x = 05m$  (Contamination by localized injection). Test04



**Figure 8:** State of concentration at a position constant  $x = 25m$  (Contamination by continue injection). Test05



### 3. Discussions

#### 3.1. Evolution Depending on Space

The peculiar shape of the curves (bell-shaped), represented in (Fig.5) and (Fig.6), reflects the gradual shift from contamination carried by the flow of liquid.

The (Fig.3) shows that during the phase of infiltration, the red bulb is highly saturated concentration in the vicinity of the unsaturated zone, but during the drainage becomes homogeneous in the aquifer. We also note that the vast majority of the pollutant mass migrates to the depths according to an inclined path.

#### 3.2. Evolution Depending on Time

If we take a coordinated known of point  $(x, z)$ , we observed a rapid increase in concentration between the twentieth day and the two hundredth day.

The increase becomes slow beyond two thousand days; this phenomenon is due to a saturation effect of the environment by the contaminants in question. The (Fig.7) shows the existence of contamination at different depths and under varying degrees.

The rapid increase in concentration then it's stabilize at some level throughout the progression of the contamination creates a permanent risk of constant penetration of pollution in the aquifers, (Fig.8).

### 4. Conclusion

The numerical solution we used for solving equations, allows us to highlight the existence of a significant part in the process of infiltration flux flowing horizontally in the unsaturated zone (ZNS), unlike the classical theory of drainage, which assumes that the flow in the unsaturated zone are assumed to be vertical. This results in agreement with the work of Silliman [8].

Thus the unsaturated zone (ZNS), plays a very important role in the process of infiltration, because it is in this interface that exchanges of water, pollutants and microorganisms into the water or the atmosphere occur. This study also highlighted the existence of transport phenomenon characterized by rapid onset of solutes in aquifers few days after applying the fluid surface in very high concentration.

One can say that this phenomenon is explained by the concept of preferential flow corresponding to flow fast. Through these circuits, the solution progresses further into the aquifers at high hydraulic conductivity.

Therefore the contamination of groundwater in the city of SOUK AHRAS reality and the time elapsed since the plant opened.

In this study, some questions emerge: What is the evolution of space pore soil under the effect of water stress and chemical? What is the exact residence time of solute in the soil? How much water is needed to wash the solutes in the soil?

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