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Trace Element Concentration Levels from Ash Pond in Semi-Infinite Aquifer

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ABSTRACT: Distribution of trace elements concentration levels due to leaching from ash pond in semi-infinite aquifer has been studied. Analytical solution has been obtained for predicting the trace elements concentration levels by applying Laplace Transformation Technique (LTT). Initially aquifer is not supposed to be solute free and it is of homogeneous nature. Source concentration at the origin of the aquifer is considered function type which gives more realistic results. Sinusoidal form of groundwater velocity has been considered and it has been observed that sinusoidal form of seepage velocity represents the seasonal variation in tropical regions. Trace elements concentration levels at various positions have been discussed keeping in the view of Bokaro Thermal Power Station (BTPS) which is located in the bank of Damoder river, Jharkhand.

INTRODUCTION

Present work deals with the trace elements concentration levels due to leaching from ash pond in semi-infinite aquifer through mathematical modeling. Mathematical modeling is an important approach to formulate the environmental problems and providing the best possible solutions so that valuable step may be taken well in advance for reducing its impact on the environment. Prediction has been carried out for the leachate data of an ash pond. Because it is the final source of leachate that is being discharged to the surface water bodies or even percolates in to the groundwater reservoir i.e. aquifer and thereby may cause groundwater contamination. As we all know the degradation of groundwater quality occurs due to infiltration of contaminants from various sources in which point sources such as Leaking septic systems, Leaky tanks or pipelines containing petroleum products, Leaks or spills of industrial chemicals at manufacturing facilities, Industrial waste, Municipal landfills, Leaky sewer lines, Fly ash from coal fired power plants etc. have some specific importance. For example, almost 90% of total Coal Combustion Residue (CCR) is disposed off to ash pond in slurry form, which requires huge amount of water. Disposal of such a huge amount of CCR is a big problem as it is not only demands for huge track of land, which could otherwise be used for agriculture, or other economic purposes but it also results in the creation of wasteland and could also lead to leaching of heavy metals and soluble salts. Leakage from ash ponds to neighboring fields and water bodies can lead to surface and groundwater contamination and it affects the human and aquatic life. An accumulation of trace elements in the aquatic environment has direct consequences to man and the ecosystem. The high level of trace elements such as Mn, Cu, Fe, Zn and Pb in the water reserves whether surface water or groundwater is a cause of concern as the health of the people and the ecosystem are at stake. For example, Zn though has low toxicity to man causes higher toxicity to fish. Cu though essential to life is toxic at very low concentration in water and is known to cause brain

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damage in mammals (DWAF, 1996b).Zn and Cu are required for metabolic activity in organism. However a very thin line is there between their essentiality and toxicity (Skidmore, 1964; Spear, 1981) Pb too has effects on human health. The ill effect of Pb includes neurological disorders especially in the foetus and in children that can lead to behavioral changes and impaired performance in IQ tests. The major effects of the presence of Fe and Mn in water or domestic use are taste of aesthetic problem. On the other hand water with Mn in excess is neither suitable for irrigation nor for the maintenance of aquatic system.

To predict the trace elements concentration levels due to leaching from ash pond in aquifer, mathematical model has been developed with suitable initial and boundary conditions. Because groundwater tends to move very slowly ranging fro 2 meter/year (0.005 meter/day) to 2 meter/day, long time period may elapse after the start of contamination, before affected water shows up in a well. For the same reason many years may be taken to rehabilitate the contaminated aquifers after the source of contamination has been eliminated. In present work trace elements concentration levels due to leaching from ash pond in semi-infinite aquifer has been studied. Initially aquifer is not supposed to be solute free i.e. at time $t = 0$ some concentration exists. Source concentration at the origin of the aquifer is considered, function type which gives more realistic result and at the other end of the aquifer is supposed to be zero. Aquifer is supposed to be homogeneous and semi-infinite which exists very much in nature. For example Gangetic basin is one of the longest groundwater reservoir in the world having an area of 250000 km^2. Sinusoidal form of velocity has been considered which represent seasonal pattern in a year in tropical region (Kumar & Kumar, 1998). A case study has been made for Bokaro Thermal Power Station (BTPS) which is located in the bank of Damoder river, Jharkhand.

MATHEMATICAL FORMULATION AND ITS ANALYTICAL SOLUTION

Let $c(x, t)$ be the trace elements concentration levels due to leaching from ash ponds in aquifer. Let u and D be the groundwater velocity and dispersion coefficient at any time t respectively: Let the trace elements concentration level at the origin of the aquifer i.e. $x = 0$ is considered a function type and concentration levels at the other end of the aquifer is supposed to be zero. Initially groundwater is not supposed to be solute free due to some internal cause or effect in the aquifer i.e. at $t = 0$ initial concentration is considered c_i/c_0. The mathematical model for existing problem is formulated as follows,

$$D\frac{\partial^2 c}{\partial x^2} - u\frac{\partial c}{\partial x} = \frac{\partial c}{\partial t} \qquad \dots (1)$$

$$u(t) = u_0 V(t) \qquad \dots (2)$$

$$c(x, t) = \frac{c_i}{c_0};\ x \geq 0, t = 0 \qquad \dots (3)$$

$$c(x, t) = \lambda c_0[1 + \exp(-qt)];\ t \geq 0, x = 0 \qquad \dots (4a)$$

$$= 0,\ t \geq 0, x \to \infty \qquad \dots (4b)$$

Where u_0 is the initial groundwater velocity at each x. The dispersion coefficient, vary approximately directly to seepage velocity for various types of porous media (Ebach & White, 1958). Also it was found that such relationship established for steady flow was also valid for unsteady flow with sinusoidally varying seepage velocity (Ebach, 1958, Rumer 1962). Let $D = au$ where the coefficient of dimension length is a and depends upon pore system geometry and average pore size diameter of porous medium. Using equation (2), we get $D = D_0 V(t)$. Here $D_0 = au_0$ is an initial dispersion coefficient. Equation (1) can now be written as,

$$D_0\frac{\partial^2 c}{\partial x^2} - u_0\frac{\partial c}{\partial x} = \frac{1}{V(t)}\frac{\partial c}{\partial t} \qquad \dots (5)$$

A new time variable (Crank, 1975), is introduced by the transformation,

$$T^* = \int_0^t V(t)dt \qquad \dots (6)$$

And equation (5) becomes,

$$D_0\frac{\partial^2 c}{\partial x^2} - u_0\frac{\partial c}{\partial x} = \frac{\partial c}{\partial T^*} \qquad \dots (7)$$

Now the set of non dimensional variables are defined as follows in terms of existing parameters but not the way as in the Leij *et al.* (1993) work on semi-infinite domain where space and time variable are non-dimensionalised in terms of parameter L (Length of aquifer) which does not occur in the problem. This flaw is taken care of in the present work,

$$C = \frac{c}{c_0}, X = \frac{x\,u_0}{D_0},\ T = \frac{u_0^2\,T^*}{D_0},\ Q = \frac{qD_0}{u_0^2} \qquad \dots (8)$$

The PDE (7) in the form of non-dimensional variable may be written as,

$$\frac{\partial^2 C}{\partial X^2} - \frac{\partial C}{\partial X} = \frac{\partial C}{\partial T} \qquad \ldots (9)$$

$$C(X,T) = \frac{c_i}{c_0^{\,2}}; X \geq 0, T = 0 \qquad \ldots (10)$$

$$C(X,T) = \lambda(2 - QT)\,;\; T \geq 0, X = 0 \qquad \ldots (11a)$$

$$= 0, T \geq 0,\; X \to \infty \qquad \ldots (11b)$$

Using the transformation,

$$C(X, T) = K(X, T)\exp\left(\frac{X}{2} - \frac{T}{4}\right), \qquad \ldots (12)$$

in equations (9)–(11) and applying Laplace transformation, we may get the solution of obtained boundary value problem as follows,

$$\bar{K}(X,p) = \left(2\lambda - \frac{c_i}{c_0^{\,2}}\right)\frac{1}{p-\frac{1}{4}}e^{-X\sqrt{p}} - \lambda Q\frac{1}{(p-\frac{1}{4})^2} e^{-X\sqrt{p}} + \frac{c_i}{c_0^{\,2}}\frac{1}{p-\frac{1}{4}}e^{-X/2} \qquad \ldots (13)$$

where $\bar{K}(X,p) = \int_0^\infty K(X,T)e^{-pT}dT,$

Taking inverse Laplace transform for (13) and putting the value of $K(X, T)$ in (12), we may obtain the desired solution as

$$C(X,T) = \frac{1}{2}\left(2\lambda - \frac{c_i}{c_0^{\,2}}\right)\left[erfc\left(\frac{x}{2\sqrt{T}} - \frac{\sqrt{T}}{2}\right) + e^X erfc\left(\frac{x}{2\sqrt{T}} + \frac{\sqrt{T}}{2}\right)\right] + \frac{c_i}{c_0^{\,2}} - \frac{1}{2}\lambda Q\left[(T-X)erfc\left(\frac{x}{2\sqrt{T}} - \frac{\sqrt{T}}{2}\right) + (T+X)e^X erfc\left(\frac{x}{2\sqrt{T}} + \frac{\sqrt{T}}{2}\right)\right] \qquad \ldots (14)$$

EXAMPLE AND DISCUSSION

Let us consider the sinusoidal form of velocity is as follows:

$$V(t) = 1 - \text{Sin}\, mt \qquad \ldots (15)$$

where m(/day) is flow resistance coefficient. For the given expression, the non-dimensional time variable T may be written as

$$T = \frac{u_0^{\,2}}{mD_0}\left[mt - (1 - \text{Cos}\, mt)\right] \qquad \ldots (16)$$

where mt = 2, 5, 8, 11, 14, 17,..., 62, 65, 68, 71, 74, 77, 80 have been chosen. For $m = 0.0165\ (\text{day})^{-1}$, (15) yields, t (days) = 121.2, 303.0, 484.8, 666.6, 848.5, 1030.3, ..., 3757.5, 3939.3, 4121.2, 4303.0, 4484.8, 4666, and 4848.4 respectively. For these values of mt, the velocity u, is alternatively minimum and maximum. Hence it represents the groundwater level and velocity minimum during the month of June and maximum during December just after six months in a year. The next data of t represents minimum and maximum records during June and December respectively in the subsequent years.

Analytical solution (14) is solved for the values c_i = 0.1, and c_0 = 1.0, q = 0.00036 /day, u_0 = 0.01 km/day; D_0 = 0.1 km^2/day; X = 10 km and λ = 54, 39 representing highest concentration levels of trace elements Na and K respectively. These values of highest concentration levels of trace elements due to leaching from ash ponds are reported for Bokaro Thermal Power Station (Kumar, 2005). The time of elimination of source of contaminants is considered at t_0 = 4900 days ($80 < mt < 83$). If the source of contamination starts at some date in the month of February ($t = 0$) before 121 days (approx.) to some date in June, during 1st year of evaluation of concentration values then the time t_0 corresponds some date in August, during 14th year of evaluation of concentration. The trace elements concentration levels are depicted graphically at mt = 62, 65, 68, 71, 74, and 77 which represents minimum and maximum records of groundwater level and velocity during June and December in 11th, 12th and 13th years respectively. The trace elements Na and K concentration levels due to leaching from ash pond in aquifer along unsteady horizontal flow of sinusoidal form is represented by the equation (14) and depicted in the Figure 1 and Figure 2 respectively. The highest concentration levels of trace elements Na and K are achieved and it can be seen in the Figure 1 and Figure 2 respectively which justify the solution of the problem. Concentration levels of other trace elements such as Mn, Cu, Fe, Zn, Pb etc. can also be observed through existing model. It has been observed that source concentration levels at the origin of the aquifer decreases with time and near by the origin it starts increases with time and distance

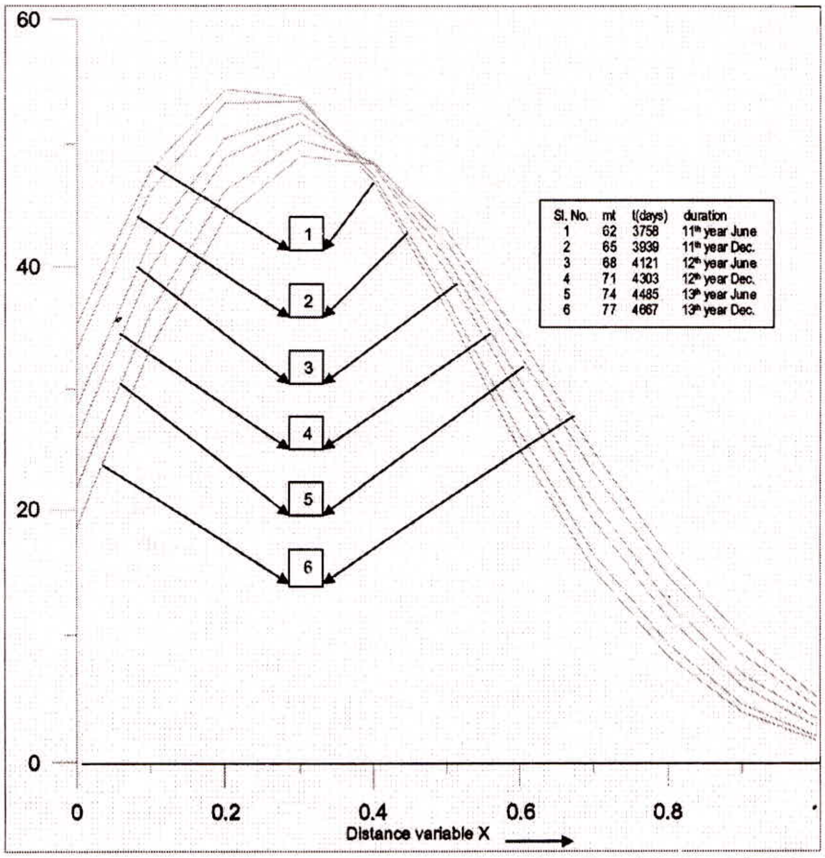

Fig. 1: Trace Element Na Concentration levels From Ash Pond in Semi-infinite Aquifer

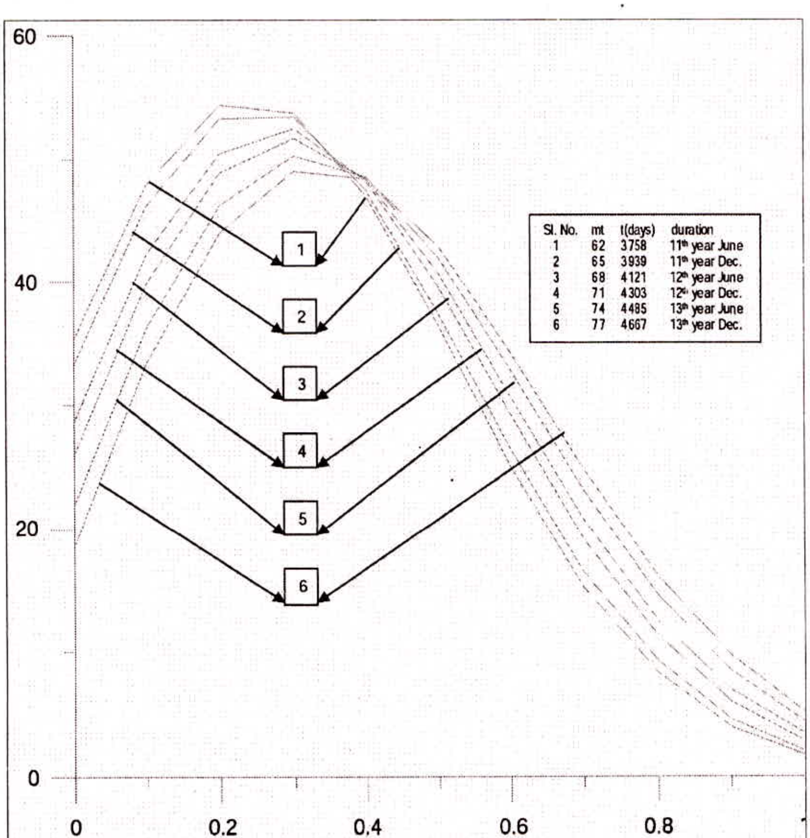

Fig. 2: Trace Element K Concentration levels From Ash Pond in Semi-infinite Aquifer

traveled till peak of trace element concentration levels is achieved. After the peak, it starts decreases with time and distance traveled and it goes on decreasing. It has also been observed that peak of trace element concentration levels decreases with time and distance traveled. Comparing the Figure 1 and Figure 2, we can also observe that Na concentration level is higher than K concentration level at each position. The decreasing tendency of trace element concentration levels may help to rehabilitate the contaminated aquifer.

CONCLUSIONS

Trace element concentration levels due to leaching from ash pond have been depicted by an analytical solution. Aquifer is considered homogeneous and semi-infinite which exists very much in nature. One-dimensional horizontal dispersion is taken in to account along unsteady groundwater flow in sinusoidal form of velocity which represent the seasonal pattern in tropical regions. The source concentration is of function type and boundary condition is used at the other end of the aquifer which is initially not solute free. Study has been made for keeping the views of Bokaro Thermal Power Station (BTPS) situated in the bank of Damoder river, Jharkhand.

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