Impact of uncertainty of biokinetic parameters on bioremediation in contaminated aquifers and human health risk – an overview

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Abstract: Human health risk assessment procedure is commonly used as a tool in relation to remedial activities at contaminated sites. This paper presents the focus and approach of a study being done to determine the impact of uncertainty in biokinetic parameters of the receptor, bioremediation and risk to human health from different exposure pathways. Aquifers contaminated with fuel hydrocarbons and chlorinated solvents, under aerobic and anaerobic biodegradation, are considered.

Key Words: Biokinetic parameters, probabilistic risk assessment, bioremediation, uncertainty

1. DESCRIPTION OF STUDY

1.1 Background

Groundwater contamination from hazardous waste can lead to detrimental effects on human health and environment. The evaluation of potential impacts of human health from different contaminants transported in groundwater is a key component in a risk assessment exercise. Risk is defined, in general, as the probability that harm will result from exposure to a contaminant transported in groundwater (Andricevic & Cvetkovic 1996). According to the United States Environmental Protection Agency Guidelines (USEPA 1989), the overall objectives of a risk evaluation process would be

- to use the analysis of baseline risks to determine the need for action at contaminated sites
- provide a basis for determining levels of chemicals that could remain on-site while be protective of public health
- provide a basis for the comparison of potential health impacts of various remedial alternatives

The risk assessment activities are performed in three different stages, namely; baseline risk assessment, refinement of preliminary remediation goals, and remedial alternatives risk evaluation (USEPA 1989). The baseline risk assessment process include data collection and evaluation, exposure assessment, toxicity assessment and risk characterisation.

1.2 Scope of Study

Risk assessments performed in the past were mainly based on single-value estimates (USEPA 1989). However, as risk is determined with several assumptions with regard to exposure and toxicity, there are uncertainty and variability inherent in estimating different parameters and therefore the current trend is to estimate risk by considering those aspects that would lead to being expressed risk as a probabilistic distribution. Some important parameters used to estimate human health risk due to contaminated groundwater are the exposure concentration, population characteristics such as water ingestion rate and body weight, etc., cancer potency factor (in relation to carcinogenic risk assessment) and reference dose (in relation to the estimation on non-cancer hazard quotient), (USEPA, 1989). The exposure concentration is also used for the determination of cost of remediation techniques, including bioremediation.

The exposure concentrations in relation to the contaminated aquifers are usually determined by using fate and transport models that are formulated based on the subsurface fate and transport processes physical, chemical and biokinetic parameters. When models are used for the determination of exposure concentrations, the use of estimated properties adds to the uncertainty in the exposure concentration estimate (USEPA 1992). Most of these models have previously been verified for single-value concentrations. Hence, these same models could be used for the estimation of exposure concentrations in the presence of input uncertainties such as physical, chemical and biokinetic parameters.

As a literature review suggested that there has been limited research in the probabilistic-based risk assessment, this study would investigate and assess the impact of uncertainty in biokinetic parameters on human health risk. Biokinetic parameters are important input parameters in fate & transport models formulated to describe the subsurface biodegradation of organic contaminants, which have not been evaluated in detail as physical and chemical parameters. The process of biodegradation has become one of the common applications used in remediation schemes for organic chemicals, due to the relative cost effectiveness in comparison to the more expensive other remediation processes. The practical application of biodegradation process in remediation schemes is termed as bioremediation.

Among the organic chemicals, the contamination of groundwater caused by gasoline and other petroleum-derived hydrocarbons released from underground storage tanks and from chlorinated solvents released from industry has been identified as a serious and widespread environmental problem in the recent past. The study would focus on using toluene and trichloroethene (TCE), representatives of common fuel hydrocarbon and chlorinated solvent, as organic contaminants for the case studies. This research is being conducted in accordance with the relevant established guidelines stipulated in the United States to investigate the impact of uncertainty in biokinetic parameters on exposure concentrations, bioremediation of contaminated aquifers and human health risks.

1.3 Research Objectives

The objectives of this study are to:

1. Develop a theoretical framework to incorporate the uncertainty in biokinetic parameters on bioremediation at hydrocarbon and chlorinated solvent contaminated aquifers
2. Demonstrate the applicability of the proposed methodology described in (1) at field-scale
3. Determine the impact of uncertainty of biokinetic parameters described in (1) in the presence of variability of population characteristics on health risk of the exposed population.

2. THEOROTICAL BACKGROUND

2.1 Bioremediation in Contaminated Aquifers

2.1.1 Biodegradation

Biodegradation is defined in general as the biologically catalysed reduction in complexity of chemicals (Alexander 1985) by microorganisms in soil, sediments, surface and groundwater. Biodegradation frequently, although not necessarily, leads to the conversion of a considerable amount of C, N, P, S and other elements in the original compound to inorganic products such as CO_2 and/or inorganic forms of N, P & S or other elements that are released by the organisms (Alexander 1985). The primary conditions to be satisfied for biodegradation process are the presence of appropriate organisms, energy source, carbon source, electron acceptors, nutrients and other acceptable conditions.

Bioremediation is the practical application of principles of biodegradation. The observed reduction in mass or concentration of compounds in groundwater over time or distance from the source of constituents of concern due to naturally occurring physical, chemical and biological processes such as biodegradation, dispersion, dilution, sorption and volatilisation is termed as natural attenuation. Enhanced bioremediation involves stimulating indigenous bacteria by adding electron acceptors and/or nutrient to the subsurface to increase bacterial growth and degradation rates. Common features of all attenuation plumes are a decline in the dissolved contaminant mass as a function of time and a decline in contaminant concentrations down gradient from the source.

2.1.2 Biodegradation mechanisms

Commonly used kinetic mechanisms that represent the biodegradation of organic chemicals in subsurface media are:

First Order Decay Model:

One of the most commonly used expressions for representing the biodegradation of an organic compound involves the use of an exponential decay relationship (Wiedemeier et al. 1999).

$$C = C_0 e^{-kt} \tag{1}$$

where C is the biodegraded concentration of contaminant after time t, C_0 is the initial concentration, and k is the rate constant

First order decay rate constants are often expressed in terms of a half-life for the chemical:

$$t_{1/2} = 0.693 / k \tag{2}$$

The first-order decay model assumes that the solute degradation rate is proportional to the solute concentration. Modellers use the first-order decay coefficient as a calibration parameter and adjust the decay coefficient until the model results are comparable to the field observations. According to Wiedemeier et al. (1999), this approach lumps uncertainties in a number of parameters such as dispersion, sorption and biodegradation into a single calibration parameter.

Electron Acceptor Limited or Instantaneous reaction Model:

The electron-acceptor-limited model (Instantaneous Reaction Model) proposed by Borden and Bedient (1986) for simulating the aerobic biodegradation of hydrocarbons is expressed mathematically as follows.

$$\Delta C = -\Delta O / F \qquad (3)$$

where ΔC is the change in contaminant concentration due to biodegradation, • O is the concentration of oxygen and F is the utilisation Factor, the ratio of oxygen to contaminant consumed.

Since the introduction of this model in aerobic degradation, many studies have also demonstrated the use of this kinetic mechanism in anaerobic degradation (Wiedemeier et al. 1999).

Monod Kinetics:

One of the most common expressions for simulating biodegradation is the hyperbolic saturation function presented by Monod and referred as Monod or Michaelis-Menten Kinetics. In groundwater, the Monod growth function is related to the rate of decrease of an organic compound (Rifai et al. 1998).

$$dC / dt = \frac{\mu_{max} MC}{Y(K_c + C)} \qquad (4)$$

where C is the contaminant concentration, Y is the yield coefficient, μ_{max} is the maximum growth rate of microorganisms, M is the microbial mass and K_c is the contaminant half-saturation constant.

The change in microbial mass is expressed as follows.

$$dM / dt = \left[\mu_{max} M.YC / (K_c + C)\right] - bM \qquad (5)$$

where b is the first decay coefficient that accounts for cell death.

The Monod rate equation described in (4) has three regions namely; first-order, mixed-order and zero-order, based on the contaminant concentration level and the value of half-saturation constant.

The uncertainty aspects of the following biokinetic parameters are being considered in this study:
1.First order decay rates under aerobic and anaerobic conditions 2. maximum growth rate of microorganisms 3. contaminant half saturation coefficient 4. yield coefficient

2.2 *Human health risk assessment*

2.2.1 Risk estimation

According to the baseline risk assessment process defined by the USEPA (1989), the process involves four important steps namely: data collection and analysis, exposure assessment, toxicity assessment and risk characterisation. Accordingly, the potential cancer and non-cancer risk are estimated using the following equations.

$$\text{Cancer Risk} = \text{CDI*SF} \quad (6)$$

$$\text{Non-cancer Risk} = \text{CDI/RfD} \quad (7)$$

where CDI is the chronic daily intake (mg/kg-d), SF is the linear low-dose cancer potency factor and RfD is the reference dose for the chemical.

The estimated values of chronic daily intake depend on the exposure pathways and the equations corresponding to ingestion of chemicals in drinking water, dermal contact with chemicals in water and inhalation of airborne (vapour phase) chemicals (USEPA 1989) are as follows

$$\text{Chronic Daily Intake due to Ingestion} = \frac{CW*IR*EF*ED}{BW*AT} \quad (8)$$

$$\text{Chronic Daily Intake due to Dermal Contact} = \frac{CW*SA*PC*ET*EF*ED*CF}{BW*AT} \quad (9)$$

$$\text{Chronic Daily Intake due to Inhalation} = \frac{CA*IR*ET*EF*ED}{BW*AT} \quad (10)$$

where CW is the chemical concentration in water (mg/l), IR is the ingestion rate (l/d), EF is the exposure frequency (d/y), ED is the exposure duration (y) , BW is the body weight (kg), AT is the average time (period over which exposure is averaged)(d), SA is the skin surface area available for contact (cm^2), PC is the chemical specific dermal permeability constant (cm/h), ET is the exposure time (h/d), CF is the volumetric conversion factor for water (1litre/1000 cm^3), CA is the chemical concentration in air (mg/m^3) and IR is the inhalation rate (m^3/h).The terms ingestion rate, body weight, skin surface area and inhalation rate are known as population parameters.

2.2.2 Probabilistic risk assessment

Recognising the uncertainty and variability involved in the risk assessment process (USEPA 1992), the estimation of probabilistic risk has been considered important. Variability refers to observed differences attributable to true heterogeneity or diversity in a population or exposure parameter, and uncertainty refers to lack of knowledge about specific factors, parameters or models (USEPA 1997). In the single-value estimation of risk, a single numerical value is selected for each variable, whereas in probabilistic risk estimation, the input values for the risk equations are experienced as random variables that could be defined by probabilistic distributions (USEPA 1997). In the case of continuous random variables, the distribution may be presented by a Probability Distribution Function (PDF), whereas for discrete random variables, the distribution may be presented by a Probability Mass Function (PMF). The outcome of a probabilistic risk assessment may be represented as a cumulation Distribution Function (CDF), that could be used for illustrating the percentile corresponding to a particular risk level of concern. In this regard, the Monte Carlo technique is widely used to characterise quantitatively the uncertainty and variability in estimated exposure and risk (USEPA 1997).

3. STUDY APPROACH

The following steps are being undertaken:

Step I: Define uncertainty of selected subsurface physical parameters (e.g. hydraulic conductivity and dispersivity) and biokinetics parameters (based on the selected biodegradation kinetic models:- first – order decay and Monod) of selected contaminants (toluene and TCE), through PDFs.

Step II: Define variability of selected population parameters (e.g. body weight, water ingestion rate), based on the selected exposure pathways, through PDFs.

Step III: Develop a theoretical framework to determine exposure concentrations under aerobic and anaerobic biodegradation, and also natural and enhanced bioremediation conditions, as PDFs at the receptor, using the uncertainty of selected subsurface physical and biokinetic (based on selected contaminant, biodegradation mechanism and electron acceptors) parameters based on Monte-Carlo technique.

Step IV: Extend above framework to determine risk at receptor, incorporating the variability of population characteristics.

Step V: Development of field-scale scenarios and application of above frameworks. The receptor concentration would be determined using selected flow and transport models which have been calibrated based on single-value estimates.

The study results may be verified analytically, where possible.

4. CONCLUSIONS

The level of impact due to uncertainty of biokinetic parameters identified by this study would be useful for the baseline risk assessment process, risk based corrective action procedure and determination of cost of bioremediation.

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The contamination not only poses an adverse impact on human and environment health, but also leads to an economic loss in NL. In 2007-08, 482 of 2269 federal contaminated sites were determined in Atlantic Canada, with 331 in NL, resulting in a large number of remediation projects.Â Factors affecting bioremediation in NL were summarized, including but not limited to the freezing/frozen soils, temperature, bio-availability of hydrocarbons, and availability of oxygen and nutrients. Recent advances in environmental applications of biosurfactants were included.Â A NL contaminated site was selected in this research, followed by a detailed site characterization. The target contaminated site was within the Lower Tank Farm (LTF) at 5 Wing Goose Bay. An Integrated Exposure, Uptake, and Biokinetic (IEUBK) as a human health risk model were applied to predict the Blood lead levels (BLLs) in Cite. Download full-text. 'I'm doing it for myself': Using a smartphone-based exercise service during the COVID-19 lockdown in the Faculty of Health Sciences, University of the Witwatersrand, South Africa. Article. Full-text available.Â Information on the uncertainty of reported dose coefficients for exposed members of the public is then needed for risk analysis. In this study, uncertainties of dose coefficients due to the ingestion of the radi Cite. Download full-text. b. a Petri dish c. a causative agent d. to contaminate e. a side effect f. a therapeutic benefit g. to inhibit the multiplication. V. Match the pairs of antonyms: 1. to prevent the growth 2. a beneficial effect 3. naturally occurring antibiotics 4. a disease-causing agent 5. to treat a diseases 6. to contaminate 7. in vivo. a. in vitro b. to purify c. a healing substance d. to cause an illness e. to stimulate the multiplication f. synthetic drugs g. a deleterious effect. Impact of environmental factors on human health 2.4. Environmental protection 2.4.1. Brief description of global problems in modern world 2.4.2.Â The negative impact of the technosphere on nature and humans can be in the form of short intense exposure such as explosions and res at potentially dangerous facilities. C. Global eects Human activity has a negative impact on the environment, and it can lead to large-scale planetary phenomena posing a threat to the entire civi-lization.Â Another morbidity risk is drinking water contaminated by chemicals. The presence of heavy metals salts and organochlorine compounds public water supply systems, as well as low barrier capacity of wastewater treatment plants is a serious threat to public health. A contaminated aquifer and bioremediation. 6. potential of bacterial species.Â Water samples from the contaminated aquifer 24 and a background aquifer were extracted and subjected to chemical, bacteriological and 25 microscopic analysis. Eighty-seven bacterial species were isolated, representing four phyla: 26 Actinobacteria (25.3%), Bacteroidetes (16.1%), Firmicutes (3.4%) and Proteobacteria 27 (55.2%). Among the Proteobacteria were Alphaproteobacteria, Betaproteobacteria, and 28 Gammaproteobacteria, in order of increasing abundance. A clear distinction between 29 uncontaminated and contaminated groundwater was observed.Â 43 human activities that have caused severe damage to groundwater resources is landfill.