REVIEW OF COMMON HAZARDOUS WASTE LANDFILL AND GROUNDWATER TRANSPORT MODELLING

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ABSTRACT: The solid waste disposal is generally done by using sanitary land fill method. In developing countries open dumping is done. Open dumping is dangerous option due to odour and disperson of waste in the form of particles in the air. Soild waste landfill is relatively safer option. The solid waste buried in the land contaminates groundwater. The bio composting of the waste provides additional benefits like manure for agriculture and reduction in the volume of waste. The other option of treating solid waste is incineration. Incineration has disadvantage of exhaust gases. The hazardous waste poses an inherent danger to personnel or the environment when exposed. Many investigators have carried out research for treatment of hazardous waste treatment. The current review summarizes research and studies on solid wastes with emphasis on hazardous waste. The conceptual model developed for the site attempted to incorporate a complex stratigraphic profile in which groundwater flow and contaminant transport is strongly controlled by a shallow aquifer. Here, different conceptual model for groundwater flow and contaminant transport is presented.

Key words*: Incineration, composting, landfill, Deviation, anaerobic treatment, vermi composting*

1. Introduction

The practice of landfill systems as a method for waste disposal in many developing countries is usually far from standard recommendations[1,2]. Landfills are sources of groundwater and soil pollution due to the production of leachate and its migration through refuse[3]. After some years, a dumpsite undergoes biologically, chemically, and hydrologically-mediated changes resulting in a weathering process of the refuse and, consequently, becomes a source of pollutants[4].

Waste disposal management remains one of the major challenges in the developing countries. Wastes, if not properly disposed of, could lead to contamination of surface and groundwater in its immediate environment[5]. The most important environmental issues today is groundwater contamination and among the wide diversity of contaminants affecting water resources, heavy metals are of particular concern, considering their high toxicity even at low concentration[6]. In recent times, the impact of leachates on groundwater and other water resources has attracted a lot of attention because of its overwhelming environmental importance. Leachates migration from waste sites or landfills and the release of pollutants from sediments pose a high risk to groundwater resource [7].

In line with the above research works, the present study aims at evaluating the environmental impacts on ground water quality associated with the operation of a common hazardous waste landfill facility (CHWLF) in Gummidipoondi industrial estate, Tiruvallur District, Tamilnadu.

2. Solid Waste Problem In India

Solid waste is major problem in Indian cities for this various study, characteristics, generation, collection, transportation and disposal for Indian cities has been carried out to evaluate the current status and identify the major problems[1]. Solid waste management is a major challenge in cities with high population density in India as the per capita generation of Muncipal solid waste has also increased tremendously with improved life style and social status of the populations in urban centers[2-4]. As more land is needed for the ultimate disposal of these solid wastes, issues related to disposal have become highly challenging[5]. Despite significant development in social, economic and environmental areas, Solid waste management systems in India have remained relatively unchanged[6]. Current Solid waste management systems are inefficient, with waste having a negative impact on public health, the environment and the economy[7]. The waste Management and Handling Rules in India were introduced by the Ministry of Environment and Forests[8].

3. Effect of Solid Waste on Water Quality

A water pollutant is a chemical or physical substance present in it at the excessive levels capable of causing harm to living organisms. The chemical hazards are the Copper, Manganese(Mg), Lead(Pb), Cadmium(Cd), Phosphate, Nitrate etc. As the public health concern, the ground water should be free from physical and chemical hazards. The people in and around the dumping site are depending upon the ground water for drinking and other domestic purposes. Other high-risk group includes population living close to a waste dump and those, whose water supply has become contaminated either due to waste dumping or leakage from landfill sites increases risk of injury, and infection[9]. In particular, domestic waste creates favourable conditions to the survival and growth of microbial pathogens[10].

Uncollected solid waste can also obstruct storm water runoff, resulting in the forming of stagnant water bodies that become the breeding ground of diseases such as Malaria, Chest Pains, Diarrhea and Cholera[11]. Direct dumping of untreated waste in rivers, seas, and lakes resulted in the accumulation of toxic substances in the food chain through the plants and animals that feed on it[12]. Certain chemicals if released untreated, e.g. Cyanides, Mercury and Polychlorinated Biphenyls (PCBs) are highly toxic and exposure can lead to disease or death. Different workers detected higher levels of organic and inorganic pollutants and heavy metals in surface and underground water and water in the vicinity of solid waste landfills[13]. It is reported that urban centers of India produce 2,20,000 tons (apprx) of solid waste per day and in almost all the cities, unscientific disposal of solid waste has created environmental pollution[14].

4. Modelling of Groundwater Flow and Mass Transport

Groundwater modelling begins with a conceptual understanding of the physical problem. The next step in modelling is translating the physical system into mathematical terms. In general, the results are the familiar groundwater flow equation and transport equations. The governing flow equation for three-dimensional saturated flow in saturated porous media is:

4. Groundwater Flow Models

Salient features of the frequently used groundwater models have been presented below. The most widely used numerical groundwater flow model is MODFLOW which is a three-dimensional model, originally developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988). It uses block-centred finite difference scheme for saturated zone. The advantages of MODFLOW include numerous facilities for data preparation, easy exchange of data in standard form, extended worldwide experience, continuous development, availability of source code, and relatively low price. However, surface runoff and unsaturated flow are not included, hence in case of transient problems, MODFLOW can not be applied if the flux at the groundwater table depends on the calculated head and the function is not known in advance.

4.1 3DFEMFAT (3-D Finite-Element Model of Flow and Transport through Saturated-Unsaturated Media)

3DFEMFAT is a 3-Dimensional Finite-Element Model of Flow And Transport through Saturated-Unsaturated Media. Typical applications are infiltration, wellhead protection, agriculture pesticides, sanitary landfill, radionuclide disposal sites, hazardous waste disposal sites, density-induced flow and transport, saltwater intrusion, etc. 3DFEMFAT can do simulations of flow only, transport only, combined sequential flow and transport, or coupled density-dependent flow and transport. In comparison to conventional finite-element or finite-difference models, the transport module of 3DFEMFAT offers several advantages: (1) it completely eliminates numerical oscillation due to advection terms, (2) it can be applied to mesh Peclet numbers ranging from 0 to infinity, (3) it can use a very large time step size to greatly reduce numerical diffusion, and (4) the hybrid Lagrangian-Eulerian finite-element approach is always superior to and will never be worse than its corresponding upstream finite-element or finite-difference method. Because of these advantages, 3DFEMFAT is suitable for applications to large field problems. It is flexibile and versatile in modeling a wide range of real- world problems.

4.2 AQUA3D (3-D Groundwater Flow and Contaminant Transport Model)

AQUA3D is a program developed to solve three-dimensional groundwater flow and transport problems using the Galerkin finite-element method. AQUA3D solves transient groundwater flow with inhomogeneous and anisotropic flow conditions. Boundary conditions may be prescribed nodal head and prescribed flow as a function of time or head-dependent flow. AQUA3D also solves transient transport of contaminants and heat with convection, decay, adsorption and velocity-dependent dispersion. Boundary conditions may be either prescribed nodal concentration (temperature) or prescribed dispersive mass (heat) flux.

4.3 AT123D(Analytical Groundwater Transport Model for Long-Term Pollutant Fate and Migration)

AT123D, analytical, transient One, Two, and Three-Dimensional Model, is an analytical groundwater transport model. AT123D computes the spatial-temporal concentration distribution of wastes in the aquifer system and predicts the transient spread of a contaminant plume through a groundwater aquifer. The fate and transport processes accounted for in AT123D are advection, dispersion, adsorption, and decay. AT123D estimates all the above components on a monthly basis for up to 99 years of simulation time. AT123D can be used as an assessment tool to help the user estimate the dissolved concentration of a chemical in three dimensions in groundwater resulting from a mass release over a source area. AT123D can handle: two kinds of source releases – instantaneous, continuous with a constant loading or time-varying releases; three types of waste–radioactive, chemicals, heat; four types of source configurations–a point source, a line source parallel to the x-, y-, z-axis, an area source perpendicular to the z-axis, a volume source; four variations of the aquifer dimensions–finite depth and finite width, finite depth and infinite width, infinite depth and finite width, infinite depth and infinite width.

4.4 BIOF&T 2-D/3-D (Biodegradation, Flow and Transport in the Saturated/Unsaturated Zones)

BIOF&T 3-D models biodegradation, flow and transport in the saturated and unsaturated zones in two or three dimensions in heterogeneous, anisotropic porous media or fractured media. BIOF&T allows real world modeling not available in similar packages. Model convection, dispersion, diffusion, adsorption, desorption, and microbial processes based on oxygen-limited, anaerobic, first-order, or Monod-type biodegradation kinetics as well as anaerobic or first-order sequential degradation involving multiple daughter species.

4.5 Chemflo (Simulates Water and Chemical Movement in Unsaturated Soils)

Chemflo is an interactive software system for simulating one-dimensional water and chemical movement in unsaturated soils. Chemflo was developed to enable decision-makers, regulators, policy-makers, scientists, consultants, and students to simulate the movement of water and chemicals in unsaturated soils. Water movement is modeled using Richards equation. Chemical transport is modeled by means of the convection-dispersion equation. These equations are solved numerically for one-dimensional flow and transport using finite differences. Results of Chemflo can be displayed in the form of graphs and tables.

4.6 ChemFlux (Finite Element Mass Transport Model)

ChemFlux is a stable finite element contaminant transport modeling software. It is a finite element software package characterized by automatic mesh generation, automatic mesh refinement and automatic time-step refinement. The solver offers speed and reduction in convergence problems. Results of benchmark tests run against MT3D confirm the effectiveness of the solver. ChemFlux is able to provide the same level of accuracy as MT3D in solutions dominated by advection while implementing the irregular geometry benefits of the finite element method. ChemFlux can also import groundwater gradients from the SVFlux groundwater modeling package. Predicting the movement of contaminant plumes through the processes of advection, diffusion, adsorption and decay is possible. The ChemFlux design module provides an elegant and simple user interface. Problem geometry and groundwater gradients may be imported from the SVFlux software.

4.7 FEFLOW

(Finite Element Subsurface Flow System)

FEFLOW is a finite-element package for simulating 3D and 2D fluid density- coupled flow, contaminant mass (salinity) and heat transport in the subsurface. It is capable of computing: Groundwater systems with and without free surfaces (phreatic aquifers, perched water tables, moving meshes);Problems in saturated-unsaturated zones;Both salinity-dependent and temperature-dependent transport phenomena (thermohaline flows); Complex geometric and parametric situations.

The package is fully graphics-based and interactive. Pre-, main- and post- processing are integrated. There is a data interface to GIS (Geographic Information System) and a programming interface. The implemented numerical features allow the solution of large problems. Adaptive techniques are incorporated.

4.8 FLONET/TRANS(2-D cross-sectional groundwater flow and contaminant transport modeling)

FLONET/TRANS is a software package for 2-D cross-sectional groundwater flow and contaminant transport modeling. The modeling environment offers all the advantages of finite-element modeling (numerical stability and flexible geometry) together with a logical and intuitive graphical interface that makes finite-element modeling fast and easy. It uses the dual formulation of hydraulic potentials and streamlines to solve the saturated groundwater flow equation and create accurate flownet diagrams for any two-dimensional, saturated groundwater flow system. In addition, it also simulates advective-dispersive contaminant transport problems with spatially-variable retardation and multiple source terms.

4.9 FLOWPATH(2-D Groundwater Flow, Remediation, and Wellhead Protection Model)

FLOWPATH for Windows is a popular model for groundwater flow, remediation, and wellhead protection. It is a comprehensive modeling environment specifically designed for simulating 2- groundwater flow and contaminant transport in unconfined, confined and leaky aquifers with heterogeneous properties, multiple pumping wells and complex boundary conditions. Some typical applications of FLOWPATH include:Determining remediation well capture zones Delineating wellhead protection areas Designing and optimizing pumping well locations for dewatering projects Determining contaminant fate and exposure pathways for risk assessment

4.10 GFLOW (Analytic Element Model with Conjunctive Surface Water and Groundwater Flow and a MODFLOW Model Extract Feature)

GFLOW is an efficient stepwise groundwater flow modeling system. It is a Windows 95/98/NT program based on the analytic element method. It models steady-state flow in a single heterogeneous aquifer using the Dupuit-Forchheimer assumption. While GFLOW supports some local transient and three-dimensional flow modeling, it is particularly suitable for modeling regional horizontal flow. To facilitate detailed local flow modeling, it supports a MODFLOW-extract option to automatically generate

MODFLOW files in a user-defined area with aquifer properties and boundary conditions provided by the GFLOW analytic element model. GFLOW also supports conjunctive surface water and groundwater modeling using stream networks with calculated baseflow.

4.11GMS (Groundwater Modeling Environment for MODFLOW, MODPATH, MT3D, RT3D, FEMWATER, SEAM3D, SEEP2D, PEST, UTCHEM, and UCODE)

GMS is a sophisticated and comprehensive groundwater modeling software. It provides tools for every phase of a groundwater simulation including site characterization, model development, calibration, post-processing, and visualization. GMS supports both finite-difference and finite-element models in 2D and 3D including MODFLOW 2000, MODPATH, MT3DMS/RT3D, SEAM3D, ART3D, UTCHEM, FEMWATER and SEEP2D. The program's modular design enables the user to select modules in custom combinations, allowing the user to choose only those groundwater modeling capabilities that are required.

4.12 Groundwater Vistas (Model Design and Analysis for MODFLOW, MODPATH, MT3D, RT3D, PEST and UCODE)

Groundwater Vistas (GV) is a sophisticated windows graphical user interface for 3-D groundwater flow and transport modeling. It couples a model design system with comprehensive graphical analysis tools. GV is a model-independent graphical design system for MODFLOW MODPATH (both steady-state and transient versions), MT3DMS, MODFLOWT, MODFLOW-SURFACT, MODFLOW2000, GFLOW, RT3D, PATH3D, SEAWAT and PEST,the model-independent calibration software. The combination of PEST and GV's automatic sensitivity analysis make GV a good calibration tool. The advanced version of Groundwater Vistas provides the ideal groundwater risk assessment tool. Groundwater Vistas is a modeling environment for the MODFLOW family of models that allows for the quantification of uncertainty. Stochastic (Advanced) Groundwater Vistas includes, Monte Carlo versions of MODFLOW, MODPATH and MT3D, Geostatistical Simulators SWIFT support advanced output options and more. GV displays the model design in both plan and cross-sectional views using a split window (both views are visible at the same time). Model results are presented using contours, shaded contours, velocity vectors, and detailed analysis of mass balance.

4.13 HST3D (3-D Heat and Solute Transport Model)

HST3D is a powerful user-friendly interface for HST3D integrated within the Argus Open Numerical Environments (Argus ONE) modeling environment. HST3D allows the user to enter all spatial data, graphically run HST3D, and visualize the results. Argus ONE integrates CAD, GIS, Database, Conceptual Modeling, Geostatistics, Automatic Grid and Mesh Generation, and Scientific Visualization within one comprehensive graphical user interface (GUI). The Heat and Solute Transport Model HST3D simulates ground-water flow and associated heat and solute transport in three dimensions. The HST3D model may be used for analysis of problems such as those related to subsurface-waste injection, landfill leaching, saltwater intrusion, freshwater recharge and recovery, radioactive waste disposal, water geothermal systems, and subsurface energy storage. The Argus ONE GIS and Grid Modules are required to run HST3D.

4.14 MicroFEM (Finite-Element Program for Multiple-Aquifer Steady-State and Transient Groundwater Flow Modeling)

The Windows version of MicroFEM is a new program, based on the DOS package Micro-Fem. It takes you through the whole process of ground-water modeling, from the generation of a finite-element grid through the stages of preprocessing, calculation, postprocessing, graphical interpretation and plotting. Confined, semi-confined, phreatic, stratified and leaky multi-aquifer systems can be simulated with a maximum of 20 aquifers. Irregular grids, as typically used by finite-element programs, have several advantages compared to the more or less regular grids used by finite-difference codes. A model with a well-designed irregular grid will show more accurate results with fewer nodes, so less computer memory is required while calculations are faster. MicroFEM offers extensive possibilities as to the ease of creating such irregular grids. Other MicroFEM features include the ease of data preparation and the presentation and analysis of modeling results. A flexible way of zone-selection and formula-assignment is used for all parameters: transmissivities, aquitard resistances, well discharges and boundary conditions for each layer. Depending on the type of model, this can be extended with layer thicknesses, storativities, spatially varying anisotropy, topsystem and user-defined parameters. To inspect and interpret model results, maps and profiles can be used to visualize contours, heads, 3D-flowlines, flow vectors, etc.

4.15 MOC (2-D Solute Transport and Dispersion in Groundwater)

MOC simulates 2-D solute transport in flowing groundwater. MOC is both general and flexible in that it can be applied to a wide range of problem types. MOC is applicable for one- or two-dimensional problems involving steady-state or transient flow. MOC computes changes in concentration over time caused by the processes of convective transport, hydrodynamic dispersion, and mixing (or dilution) from fluid sources. MOC assumes that gradients of fluid density, viscosity and temperature do not affect the velocity distribution. However, the aquifer may be heterogeneous and/or anisotropic. MOC is based on a rectangular, block-centered, finite-difference grid. It allows the specification of injection or withdrawal wells and of spatially-varying diffuse recharge or discharge, saturated thickness, transmissivity, boundary conditions and initial heads and concentrations. MOC incorporates first-order irreversible rate-reaction; reversible equilibrium controlled sorption with linear, Freundlich, or Langmuir isotherms; and reversible equilibrium-controlled ion exchange for monovalent or divalent ions.

4.16 MOCDENSE (Two-Constituent Solute Transport Model for Groundwater Having Variable Density)

MOCDENSE is a modified version of the ground-water flow and solute-transport model of Konikow and Bredehoeft which was designed to simulate the transport and dispersion of a single solute that does not affect the fluid density. This modified version of MOCDENSE simulates the flow in a cross-sectional plane rather than in an areal plane. Because the problem of interest involves variable density, the modified model solves for fluid pressure rather than hydraulic head in the flow equation; the solution to the flow equation is still obtained using a finite- difference method. Solute transport is simulated in MOCDENSE with the method of characteristics as in the original model. Density is considered to be a function of the concentration of one of the constituents.

4.17 MODFLOW (Three-Dimensional Finite-Difference Ground-Water Flow Model)

MODFLOW is the name that has been given the USGS Modular Three- Dimensional Ground-Water Flow Model. Because of its ability to simulate a wide variety of systems, its extensive publicly available documentation, and its rigorous USGS peer review, MODFLOW has become the worldwide standard ground-water flow model. MODFLOW is used to simulate systems for water supply, containment remediation and mine dewatering. When properly applied, MODFLOW is the recognized standard model. Ground-water flow within the aquifer is simulated in MODFLOW using a block- centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of both. Flows from external stresses such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through riverbeds can also be simulated.

4.18 MODFLOW SURFACT(MODFLOW-Based Ground-Water Flow and Contaminant Transport Model)

A new flow and transport model, MODFLOW SURFACT, is based on the USGS MODFLOW code, the most widely-used ground-water flow code in the world. MODFLOW, however, has certain limitations in simulating complex field problems. Additional computational modules have been incorporated to enhance the simulation capabilities and robustness. MODFLOW SURFACT is a seamless integration of flow and transport modules.

4.19 MODFLOWT (An Enhanced Version of MODFLOW for Simulating 3-D Contaminant Transport)

MODFLOWT is an enhanced version of the USGS MODFLOW model which includes packages to simulate advective-dispersive contaminant transport. Fully three-dimensional, MODFLOWT simulates transport of one or more miscible species subject to adsorption and decay through advection and dispersion. MODFLOWT performs groundwater simulations utilizing transient transport with steady-state flow, transient flow, or successive periods of steady-state flow. Groundwater flow data sets created for the original MODFLOW model function without alteration in MODFLOWT; thus extension of modeling projects to simulate contaminant transport is very easy using MODFLOWT. It is thoroughly tested and has been bench-marked against other transport codes including MT3D, SWIFT and FTWORK. A comprehensive and pragmatic approach to contaminant transport has been incorporated into MODFLOWT which allows for three distinct directional dispersivity values, multiple chemicals and a rigorous treatment of the hydrodynamic dispersion tensor.

4.20 MODFLOWwin32(MODFLOW for Windows)

MODFLOWwin32 has all the features of other MODFLOW versions including the newest packages added over the years since MODFLOW's original release by the USGS. These new packages include the Stream Routing Package, Aquifer Compaction Package, Horizontal Flow Barrier Package, BCF2 and BCF3 Packages, and the new PCG2 solver. In addition, MODFLOWwin32 will create files for use with MODPATH (particle-tracking model for MODFLOW) and MT3D (solute transport model). MODFLOWwin32, as its name implies, is a 32- bit program designed to address all the memory available to Windows. MODFLOWwin32 will run in all versions of Windows including Version 3.1, 3.11, Windows 95, 98 and Windows NT.

4.21 MODPATH(3-D Particle Tracking Program for MODFLOW)

MODPATH, "A Particle Tracking Post-Processing Package for MODFLOW, the USGS 3-D Finite-Difference Ground-Water Flow Model (MODFLOW)," is a widely-used particle-tracking program.

4.22 MOFAT(Multiphase (Water, Oil, Gas) Flow and Multicomponent Transport Model)

MOFAT for Windows includes a graphical preprocessor, mesh editor and postprocessor with on-line help. Simulate multiphase (water, oil and gas) flow and transport of up to five non-inert chemical species in MOFAT. Model flow of light or dense organic liquids in three fluid phase systems. Simulate dynamic or passive gas as a full three-phase flow problem. Model water flow only, oil-water flow, or water-oil-gas flow in variably-saturated porous media. MOFAT achieves a high degree of computational efficiency by solving flow equations at each node (on the finite-element mesh) only for phases that are undergoing changes in pressures and saturations above specified tolerances using a new adaptive solution domain method. Therefore, if NAPL is absent or exists at a residual saturation, MOFAT will locally eliminate those flow equations. MOFAT analyzes convective-dispersive transport in water, NAPL, and gas phases by assuming local equilibrium or nonequilibrium partitioning among the fluid and solid phases. MOFAT considers interphase mass transfer and compositional dependence of phase densities. A concise but accurate description of soil capillary pressure relations is used which assures natural continuity between single-phase, two- phase and three-phase conditions.

4.23 MS-VMS(MODFLOW-Based Visual Modeling System with Comprehensive Flow and Transport Capability)

MS-VMS is a comprehensive MODFLOW-based ground-water flow and contaminant transport modeling system. The USGS modular ground-water flow model, MODFLOW, is the most widely-used ground-water flow model in the world. But, in its original form, MODFLOW has certain limitations and cannot be used to simulate some complex problems encountered regularly by modelers, hydrogeologists, and engineers in the field. MS-VMS overcomes these limitations.

4.24 MT3D (A Modular 3D Solute Transport Model)

MT3D is a comprehensive three-dimensional numerical model for simulating solute transport in complex hydrogeologic settings. MT3D has a modular design that permits simulation of transport processes independently or jointly. MT3D is capable of modeling advection in complex steady-state and transient flow fields, anisotropic dispersion, first-order decay and production reactions, and linear and nonlinear sorption. It can also handle bioplume-type reactions, monad reactions, and daughter products. This enables MT3D to do multi-species reactions and simulate or assess natural attenuation within a contaminant plume. MT3D is linked with the USGS groundwater flow simulator, MODFLOW, and is designed specifically to handle advectively-dominated transport problems without the need to construct refined models specifically for solute transport.

4.25 PEST(Parameter Estimation for Any Model)

PEST is a nonlinear parameter estimation and optimization package. It can be used to estimate parameters for just about any existing model whether or not you have the model's source code. PEST is able to "take control" of a model, running it as many times as it needs while adjusting its parameters until the discrepancies between selected model outputs and a complementary set of field or laboratory measurements is reduced to a minimum in the weighted least-squares sense.

4.26 PESTAN(Pesticide Transport Model)

PESTAN, Pesticide Transport, is a U.S. EPA program for evaluating the transport of organic solutes through the vadose zone to groundwater. PESTAN uses an analytical solution to calculate organic movement based on a linear isotherm, first-order degradation and hydrodynamic dispersion. Input data includes water solubility, infiltration rate, bulk density, sorption constant, degradation rates, saturated water content, characteristic curve coefficient, saturated hydraulic conductivity and dispersion coefficient.

4.27 Processing Modflow (PMWIN)
(Graphical Interface for MODFLOW, MODPATH, PMPATH, MT3D, PEST, and UCODE)

Processing MODFLOW for Windows (PMWIN) is a complete simulation system. It comes complete with a professional graphical preprocessor and postprocessor, the 3-D finite-difference ground-water models MODFLOW-88,MODFLOW-96, and MODFLOW 2000; the solute transport models MT3D, MT3DMS, RT3D and MOC3D; the particle tracking model PMPATH 99; and the inverse models UCODE and PEST-ASP for automatic calibration. A 3D visualization and animation package, 3D Groundwater Explorer, is also included.

4.28 POLLUTE (Finite-Layer Contaminant Migration Model - Landfill Design)

POLLUTE can be used for fast, accurate, and comprehensive contaminant migration analysis. It implements a "1½-dimensional" solution to the advection-dispersion equation. Unlike finite-element and finite-difference formulations, POLLUTE does the numerical stability problems of alternate approaches. Landfill designs that can be considered range from simple systems on a natural clayey aquitard to composite liners with multiple barriers and multiple aquifers. In addition to advective-dispersive transport, POLLUTE can consider adsorption, radioactive and biological decay, phase changes, and transport through fractures. The Graphical User Interface makes the editing, execution, and printing of data easy and flexible. This interface also has options to quickly design landfills with primary composite barriers or primary and secondary composite barriers.

4.29 PRINCE(7 Mass Transport and 3 Flow Models)

PRINCE is a well-known software package of ten analytical groundwater models originally developed as part of an EPA 208 study. There are seven one-, two- and three-dimensional mass transport models and three two-dimensional flow models in PRINCE. These groundwater models have been rewritten from the original mainframe FORTRAN codes in graphics-rich and PC-friendly C. Two popular analytical models have been added to the original collection, and the ability to import digitized or AutoCAD-produced DXF site map files has been added. The result is a widely acclaimed, user-friendly, menu-driven package with built-in high resolution graphics for X-Y, 2-D contour and 3-D surface plots.

4.30 PRZM3 (Pesticide Transport Model - Exposure Assessments)

PRZM3 links two models, PRZM and VADOFT to predict pesticide transport and transformation down through the crop root and vadose (unsaturated) zone to the water table. PRZM3 incorporates soil temperature simulation, volatilization and vapor phase transport in soils, irrigation simulation, and microbial transformation. PRZM is a one-dimensional finite-difference model which uses a method of characteristics (MOC) algorithm to eliminate numerical dispersion. VADOFT is a one-dimensional finite-element code that solves Richards' equation for flow in the unsaturated zone. The user may make use of constituting relationships between pressure, water content, and hydraulic conductivity to solve the flow equation. PRZM3 is capable of simulating multiple pesticides or parent-daughter relationships. PRZM3 is also capable of estimating probabilities of concentrations or fluxes in or from various media for the purpose of performing exposure assessments. PRZM and VADOFT are linked together with the aid of a flexible execution supervisor that allows the user to build models that are tailored to site- specific situations. Monte Carlo pre and postprocessors are provided in order to perform probability-based exposure assessments.

4.31 RBCA Tier 2 Analyzer(2D Groundwater Flow and Biodegradation Model)

The RBCA Tier 2 Analyzer is a two-dimensional groundwater model with a comprehensive selection of contaminant transport simulation capabilities including single or multiple species sequential decay reactions such as reductive dechlorination of PCE instantaneous or kinetic-limited BTEX biodegradation with single or multiple electron acceptors and equilibrium or non-equilibrium sorption.

4.32. SEAWAT (Three-Dimensional Variable-Density Ground-Water Flow)

The SEAWAT program was developed to simulate three-dimensional, variable- density, transient ground-water flow in porous media. The source code for SEAWAT was developed by combining MODFLOW and MT3DMS into a single program that solves the coupled flow and solute-transport equations. The SEAWAT code follows a modular structure, and thus, new capabilities can be added with only minor modifications to the main program. SEAWAT reads and writes standard MODFLOW and MT3DMS data sets, although some extra input may be required for some SEAWAT simulations. This means that many of the existing pre- and post-processors can be used to create input data sets and analyze simulation results. Users familiar with MODFLOW and MT3DMS should have little difficulty applying SEAWAT to problems of variable-density ground-water flow.

4.33 SESOIL (Long-Term Pollutant Fate and Migration in the Unsaturated Zone)

SESOIL is a seasonal compartment model which simulates long-term pollutant fate and migration in the unsaturated soil zone. SESOIL describes the following components of a user-specified soil column which extends from the ground surface to the ground-water table.Hydrologic cycle of the unsaturated soil zone. Pollutant concentrations and masses in water, soil, and air phases. Pollutant migration to groundwater. Pollutant volatilization at the ground surface. Pollutant transport in washload due to surface runoff and erosion at the ground surface. SESOIL estimates all of the above components on a monthly basis for up to 999 years of simulation time. It can be used to estimate the average concentrations in groundwater. The soil column may be composed of up to four layers, each layer having different soil properties which affect the pollutant fate. In addition, each soil layer may be subdivided into a maximum of 10 sublayers in order to provide enhanced resolution of pollutant fate and migration in the soil column. The following pollutant fate processes are accounted for: Volatilization, Adsorption, Cation Exchange, Biodegradation, Hydrolysis and Complexation.

4.34 SLAEM / MLAEM(Analytic Element Models - Model Regional Groundwater Flow in Systems of Confined Aquifers, Unconfined Aquifers and Leaky Aquifers)

The AEM family of computer programs, SLAEM, MLAEM/2, and MLAEM, are based on the Analytic Element Method developed by Dr. O.D.L. Strack. The computer programs are intended for modeling regional groundwater flow in systems of confined, unconfined, and leaky aquifers. SLAEM (Single Layer Analytic Element Model) is the single-layer version of the program. MLAEM/2 (Multi Layer Analytic Element Model) can access two layers while the number of layers supported by MLAEM is limited only by hardware. All programs run under Microsoft Windows 95,98 and NT. The programs are native windows applications and are accessed via a modern and flexible Graphical User Interface (GUI), as well as via a command-line interface. The latter capability makes it easy to drive the program from other programs such as Arc-View, ARC/INFO, and PEST. The programs create files from data entered graphically via the GUI; these files can be read in later. The programs read DXF-files and produce BNA files that may be read by other programs such as SURFER.

4.35 SOLUTRANS (3-D Analytic Solute Transport Model)

SOLUTRANS is a 32-bit Windows program for modeling three-dimensional solute transport based on the solutions presented by Leij et al. for both equilibrium and non-equilbrium transport. The interface and input requirements are so simple that it only takes a few minutes to develop models and build insight about complex solute transport problems. With SOLUTRANS you can, in a matter of minutes, model solute transport from a variety of source configurations and build important insights about key processes. SOLUTRANS offers a quick and simple alternative to complex, time-consuming 3-D numerical flow and transport models.

4.36 SUTRA(2-D Saturated/Unsaturated Transport Model)

SUTRA is a 2D groundwater saturated-unsaturated transport model, a complete saltwater intrusion and energy transport model. SUTRA simulates fluid movement and transport of either energy or dissolved substances in a subsurface environment. SUTRA employs a two-dimensional hybrid finite-element and integrated finite-difference method to approximate the governing equations that describe the two interdependent processes that are simulated: (1) fluid density- dependent saturated or unsaturated groundwater flow and either (2a) transport of a solute in the groundwater, in which the solute may be subject to equilibrium adsorption on the porous matrix and both first-order and zero-order production or decay, or (2b) transport of thermal energy in the groundwater and solid matrix of the aquifer. A 3-D version of SUTRA has been recently released.

4.37 SVFlux 2D (Saturated/Unsaturated Automated 2D/3D Seepage Modeling Software)

SVFlux 2D represents the next level in seepage analysis software. Designed to be simple and effective, the software offers features designed to allow the user to focus on seepage solutions, not convergence problems or difficult mesh creation. Great care has been taken to model geometry CAD-style input after the popular AutoCAD(TM) software. Freeform boundary equations and an optional soil database of over 6,000 soils to choose from further simplify model design. The finite element solution makes use of fully automatic mesh generation and mesh refinement to solve the problem quickly as well as indicating zones of critical gradient.

4.38 SWIFT (3-D Model to Simulate Groundwater Flow, Heat, Brine and Radionuclide Transport)

SWIFT is a fully-transient, three-dimensional model to simulate groundwater flow, heat (energy), brine and radionuclide transport in porous and fractured geologic media. The primary equations for fluid (flow), heat and brine are coupled by fluid density, viscosity and porosity. In addition to transient analysis, SWIFT offers a steady-state option for coupled flow and brine. The equations are solved using central or backward spatial and time weighting approximations by the finite-difference method. In addition to Cartesian, cylindrical grids may be used. Contaminant transport includes advection, dispersion, sorption and decay, including chains of constituents. Both dual-porosity and discrete-fracture representations along with rock matrix interactions may be simulated. The nonlinearities resulting from water table and variable density are solved iteratively.

5. Literature Review

Aziz et al. (2010)discussed the Leachate constitutes a complex matrix of various chemical substances, including dissolved organic matter, inorganic salts, organic trace impurities, and heavy metals, each of which appears in different concentrations due to the physical, chemical, and microbiological processes taking place in the deposited waste.

Chofqi et al. (2004) and Regadío et al. (2012)discussed many factors influence the leachate composition, among them the type of deposited waste, the method of exploiting the landfill, and the availability of oxygen, as well as the hydrogeological conditions and the age of the landfill.

Brennan et al. (2016)find the inspection of a municipal waste landfill site is advisable due to the potential threat that leachate poses to the surrounding environment, including in particular the groundwater as a consequence of its infiltration by the deposited waste.

Kjeldsen and Christophersen (2001) and Deshmukh and Aher (2016) defined the risk of pollution of the groundwater by the leachate from the landfill sites is considered to be the most significant risk for the natural environment and human health related to the tipping of waste.

Koshy et al. (2007) This threat is harmful to both surface and groundwater sources and results from the toxicity of the leachate, and its subsequent migration, which is a serious problem of environmental pollution.

Van Gulck et al., (2004) Minimization of groundwater contamination below the landfill should be ensured by the leachate collection system and reinforced by suitable operation of the landfill site.

Singh et al. (2016)defined appropriate operation of a landfill site, maintaining the leachate at the lowest level possible, is the key element of the protection of the water environment neighbouring landfill sites. This is important in the context of treatment of groundwater as a major source of water supply in both urban and rural areas.

According to researchers **Mor et al. (2006) and Deshmukh and Aher (2016)**, a high level of electrical conductivity in groundwater is attributable to the impact of a nearby landfill site.

Esakku et.al., (2007) stated the essential to protect ground and surface waters and soil from contamination due to leachate percolation in and around the dumpsites.

Singh et.al, (2008) analyzed samples of solid waste, leachate and groundwater and stated that groundwater pollution due to leachate is dominant over natural processes in the vicinity of the landfill site. High concentration of Total Dissolved Solids, electrical conductivity, hardness, nitrate, chloride, and sulphate were found in groundwater near landfill.

Agamuthu et al.,(2001)stated the metal ions released in water become distributed into the surrounding areas by lateral and vertical movements in the ground.

Jorstd et al (2004) stated that decrease in concentration while moving away from the landfill is mainly due to dispersion, dilution and sorption process.

Padmavathi (2008) opined that the Perungudi dumping yard is one of the major menace for the local residents. Small scale investigation at trace levels of water and soil for various chemical constituents has been carried out. It is noticed that within three years span the contamination level increased three fold.

Kale et al (2010) studied a dumpsite in the hard rock terrains of a basaltic aquifer and stated that the flow is slow and unstable due to constricted passages. But a negative consequence of mechanism is that the pollutants maintain a constant level of contamination and their toxicities. The reviewed literature indicates that unlined, non-engineered dumpsite are prevalent in the developing countries. This leads to environmental degradation. Dumpsite selection and method of dumping needs to be critically reviewed and protective measures are to be taken to prevent the groundwater contamination.

6. Groundwater Model

Models are conceptual descriptions or approximations that describe physical system using mathematical equations. The applicability of a model depends on how closely the mathematical equations approximate the physical system being modeled. The solution of a mathematical model of a problem takes the form of temporal and spatial distribution of the state variables of interest within the problem's prescribed time and space domains.

7. Model Conceptualization

The foremost step in modeling is to construct a conceptual model of the problem and of the related domain. The conceptual model consists of set of assumptions that reduce the real problem and the real domain to a simplified version.

Assumptions related to such characteristics are

- The domains hydrogeology and stratigraphy
- The dimensionality of the model and the geometry of the boundary of the domain
- The behavior of the system: steady state or time dependent
- The kind of soil and rock materials comprising the domain, as well as inhomogenity and anisotropy of the materials
- The extensive quantities transported within the domain
- The relevant transport mechanism within the domain
- The relevant chemical, physical and biological processes that takes place in the domain
- The flow regimes of the involved fluids
- The presence of source and sinks of fluids and contaminants within the domain and their nature The initial conditions within the domain, and condition on its boundaries.

The next step is to develop a mathematical model with the conceptual model.

Having constructed the mathematical model, in terms of relevant state variables it can be solved analytically or by using numerical methods. However, because of the complex nature of the groundwater equations, numerical methods are usually employed for solving the mathematical model. This means that various methods are used to transform the mathematical model into a numerical one, in which partial differential equations are represented by their numerical counterparts. A computer program or a code is required to solve the numerical model. Codes are available both for flow and contaminant transport problems.

Computer codes have been developed by individual researchers, by governmental agencies, or by commercial entities. The following is a brief review of some of the most widely used computer codes. Modular Finite-Difference Ground-Water Flow Model (MODFLOW) simulates three-dimensional groundwater flow by using a cellcentered Finite Difference Method. It was first released by the U.S. Geological Survey in 1984 as a public domain computer code (McDonald and Harbaugh 1984). MODPATH (Pollock 1994) is a particle tracking postprocessing computer code for MODFLOW. This program is used to trace the pathlines, based on the assumption of advective transport only. Modular 3-D multi-species transport model (MT3DMS) for simulation of advection, dispersion and chemical reactions of contaminants in ground-water system code was first released as MT3D by the U.S. Environmental Protection Agency (Zheng 1990). MT3D interfaces directly with MODFLOW for the flow solution. For solute transport, it utilizes an Eulerian Lagrangian scheme, based on a forward tracking method of characteristics (MOC) (Konikow and Bredehoeft 1978), or a modified method of characteristics (MMOC), as well as on a combination of these two methods (HMOC). MT3D was later extended and released by the U.S. Army Corps of Engineers, Engineering and Research Development Centre (Zheng and Wang, 1999), as MT3DMS, where the 'MS' stands for multispecies transport. Parameter Estimation (PEST) was developed by Doherty (2005) as a modelindependent nonlinear computer code.

Finite Element Subsurface Flow and Transport Simulation System (FEFFLOW) is a commercial software package which simulates threedimensional, density-dependent, saturated-unsaturated flow, chemical mass transport, and solid and fluid heat transport in porous media. Model for 2D or 3D Saturated-Unsaturated, Variable-Density Ground-Water Flow, with Solute or Energy Transport (SUTRA) is a Galerkin based finite element code that solves ground water flow and transport problems under saturated and unsaturated conditions.

Coupled Variable Density and Saturation 3D Model (CODESA3D) is a finite element code, developed by the Center for Advanced Studies, Research and Development in Sardinia, Italy. It solves the convectivedispersive, variable density transport equation in saturated and variably saturated porous media (Gambolati et al 1999).

BIOPLUME is a two-dimensional computer code for simulation contaminant transport of a single and multiple hydrocarbons with oxygen limited and reactant limited bio-reaction (Rafai et al 1998), developed by EPA. Its transport code is based on the USGS MOC.

A Multispecies Solute-Transport Model with Biodegradation (BIOMOC) is a USGS two-dimensional code based on MOC. It simulates the transport and biotransformation of multiple reacting solutes (Essaid and Bekins 1997).

The reviewed groundwater flow and contaminant transport models show that a large number of codes are available and an appropriate code has to be selected for the chosen problem. As there are different codes, with overlapping capabilities, the selection is generally based on the popularity of their adoption and the broad spectrum of coverage. Each code may serve a different purpose, and there is no universal code.

8. Applications in Groundwater Modelling

Gburek (1999) [1] modelled the pollutant transport within a layered and fractured aquifer of an upland agricultural watershed in Pennsylvania, USA. The simulation results from a previous study by the same author **(Gburek, 1998)** on a groundwater flow simulation using Visual MODLFOW under springtime steady-state recharge was used as the basis for the study of areal-format water-shed flow paths.

Kuchling (2000) [3] modelled the groundwater flow and TDS plume transport arising from mining operations at Daivik diamonds project in Canada.

Roadcap (2001) [4] simulated the effects of pumpage from a series of ten groundwater wells on a particular aquifer and its surrounding wells.

Rao (2001) [2] assessed the pollution of groundwater flowing downstream of an industrial site and modelled the flow and contaminants. Simulations were developed for 20 years (1977 to 1997) with data from previous records. The stream-aquifer interaction was found to be the reason for the faster migration of pollutants.

Jia (2003) [6] simulated the groundwater flow in the Luancheng county of Hebei Province, China to understand the groundwater level fluctuations.

Kim (2003) developed a GIS based Pre- and Postprocessing tool for Visual MODFLOW to manage input data for flow analysis.

Meriano (2003) [7] developed a groundwater flow model for a drainage basin in Canada. With their forecast they demonstrated the susceptibility of deeper aquifers to urban contaminants and suggested the importance of long term planning for water quality.

Yunjie (2003) used Visual MODFLOW to simulate groundwater flow with the prevailing hydrogeological conditions at a sandstone-type uranium deposits.

Tiwary (2005) [8] modelled the migration of hexavalent chromium from chromite deposits of the Sukinda valley in Odisha, India. The path lines of migration of Cr6+ were simulated for 20 years.

Bin (2005) applied well boundaries package of the software to simulate 23 faults (rocks) of compressoshear and water-resisting types on the path of groundwater flow to study the effect of faults on the flow.

Hu (2006) [9] explores the application constraints with Visual MODFLOW in groundwater simulations.

Yuan-fang (2006) studied the groundwater flow and levels around a river in China to ensure its quantity to meet the water demand of a city.

Yizhong (2007) simulated a two-dimensional unconfined groundwater flow and the migration of nitrate contaminant for a period of 42 years in Shijia Zhuang, China.

Fei (2008) simulated the groundwater flow for a plain reservoir in Sheyang, China. They predicted the exploitable groundwater capacity with different water levels in the reservoir.

Rejhani (2008) [12] simulated a 2-D groundwater flow to study the overexploitation of groundwater and to analyse the aquifer response to various pumping strategies in the Balasore coastal basin, India. Five pumping scenarios were used for the simulation.

Zume (2008) [13] modelled the groundwater flow in the semiarid north-western Oklahoma, USA to assess the impact of exploiting groundwater on the streamflow depletion in the Alluvium and Terrace aquifer of the Beaver-North Canadian River in the north-western Oklahoma, USA. With the help of streamflow routing package of the software, changes induced by pumping on base flow and stream leakage were studied.

LIU (2009) [14] developed a three-dimensional seepage model of karst water and simulated the seepage flow field and the water level regime variation. The study was carried out to ensure the safety in coal mining.

Mondal (2009) [16] developed a mass transport model for the migration of tannery effluent contaminants around a tannery industrial belt. It was reported that the migration phenomenon was affected mainly by advection rather than dispersion. The contaminant transport emanated from the tannery belt and moved towards eastern side of a river downstream.

Jovanovic (2009) [17] used Visual MODFLOW to calculate the spatial distribution of NOx concentrations in groundwater. The research work was to study the impact of nitrogen dynamics on land and ground at Riverlands Nature Reserve, South Africa.

Saravanan (2010) studied the migration of leachate plume from the Kodungaiyur landfill in Chennai, India and simulated the transport of heavy metals for a period of 10 years.

Shi (2010) [18] applied Visual MODFLOW to evaluate the impact caused by the leakage of a sewage plant accident pool on groundwater. Ammoniacal Nitrogen (NH3-N) migration from the accident spillage was simulated.

Faghihi (2010) [22] predicted the reaction of an aquifer to different environmental stress scenarios in the Qazvin plain of Iran.

Feng (2010) [20] predicted the groundwater depression funnel and variations in groundwater levels due to different exploitation extents.

Sarvarian (2010) [19] used Visual MODFLOW to identify capture zones for wells in Urmia plain, Iran. MODPATH package of the software was used for this work. Also, they determined the influence of injection wells of wastewater on capture zones of pumping wells.

Vandecasteele (2010) studied a catchment in Northern Ethiopia during the rainy season in 2006. They developed a groundwater flow model for the catchment with a perched water table. The soil water budget was calculated for the period 1995-2006.

Lei (2011) studied the seepage field along the centre line of an airport runway. Four different engineering conditions by excavating ditches were presented and simulated for the effect of floodwater on the groundwater seepage field on the runway.

Yugen (2011) forecasted the water inflow impact in a bauxite mine in China. The forecast was used as a precautionary study to prevent water-in rush accident in the mine.

Saghravani (2011) [24] predicted the transport of phosphorus around a landfill in Malaysia for 10 years.

Da (2011) built a model to simulate the pit dewatering process for a river delta region. The model result was suggested as a credible design reference for the construction of the dewatering scheme.

Saravanan (2011) [21] modelled groundwater flow for textile effluent affected areas in Tirupur basin, India and demarcated the groundwater protection zones. These modelled zones were ranked and their need for keeping them pollution-free was stressed.

Varalakshmi (2011) [28] modelled the groundwater flow for a hard rock aquifer to determine the average input, output and the withdrawal levels of water in the aquifer system.

Rao (2011) assessed the groundwater contamination around a dumpsite near TCCL at Ranipet, India. Migration of TDS and chromium plumes in the groundwater were simulated for 30 years.

Paramesswari (2012) [27] used Visual MODFLOW to prepare a pictorial representation of the geohydrological profile of their study area to represent the layers of soil in the study area.

Liolios (2012) [29] modelled the fate and transport of Biochemical Oxygen Demand (BOD) for a horizontal subsurface flow constructed wetlands under Mediterranean conditions. Test runs were performed for various vegetation, porous media size, temperature and hydraulic retention time (HRT) conditions.

Xi-lian (2012) used the software to study the changes in groundwater flow field after the construction of a factory in Qufu city, China. Lead contamination was simulated for two different conditions created by the construction work.

Haque (2012) modelled the recharge fluctuation rates of a groundwater source in Bangladesh. Also, they showed the reasons for groundwater shortage during dry seasons using modelling.

Ismail (2012) simulated the performance of a horizontal well to understand the optimum pumping rate that would safely achieve the desired drawdown in an area surrounding the horizontal collector well. Horizontal well hydraulic properties were assumed and a transient groundwater flow model was developed. Also, a steady-state model was built to predict the capture zone characterization.

Wang (2013) [32] used Visual MODFLOW as an Environmental Impact Assessment (EIA) tool. They ascertained the impact of soil and water conservation in weakening the surface run-off and strengthening the underground run-off using modelling.

Rajamanickam (2013) [38] modelled the groundwater around the Amaravathi river basin of Karur District, Tamil Nadu to study the effect of discharging partially treated effluents from textile bleaching and dyeing units. Total Dissolved Solids (TDS) migration was simulated for 15 years under five different scenarios.

Kant (2013) [34] modelled the groundwater levels in the Sonar sub-basin in Madhya Pradesh. The aquifers situated in the alluvial plains of Madhya Pradesh were modelled to find the fluctuations in water levels.

Beltran (2013) [33] used Visual MODFLOW with ArcGIS and Surfer to simulate the sub-surface water flow in and around a solid waste dumpsite in Mexico and modelled the migration path lines of contaminants.

Zhai (2014) [40] assessed the drainage of a limestone aquifer. The study was carried out in a mining area. The model result precisely identified the poor drainage condition in the eighth mining area and suggested remedial measures.

Kumar (2014) [39] developed a groundwater flow model to quantify groundwater in Choutuppal Mandal, Andhra Pradesh. The water budget estimate was also made.

Parameswari (2015) [41] analysed the leachate migration from a dump yard at Perungudi, Chennai, India. The groundwater flow model was calibrated for transient conditions and chloride migration was simulated for 12 years. The model results were helpful to assess the contaminant's influence on the water supply wells located downstream of the landfill.

Guan (2015) predicted the groundwater level decline downstream of a river basin under different conditions and found out the period during which overexploitation of groundwater was made.

Surinaidu (2015) [36] applied Visual MODFLOW to study groundwater seepage issues in subsurface tunnels. They created a three dimensional finite difference model with the help of inferences made from hydro-geo-morphological features and geological lineaments to investigate the groundwater seepages and then suggested solutions.

Qadir (2016) [43] studied the groundwater sustainability for agricultural activities near the Indus River in Pakistan. Water table depth maps and groundwater budget calculations were interpreted. The condition for the simulation was taken by considering the before and after scenarios of a river canal construction. The model results forecasted the continued drawdowns for the entire period of simulation (35 years).

Persson (2016) [44] modelled the transport of perfluorooctanesulfonic acid (PFOS) in groundwater at the old fire drill site of Bromma Stockholm airport in Sweden. They found that it would take approximately 570 years for the PFOS to be carried by groundwater from the site to the airport area.

Baharuddin (2016) [48] simulated the sub-drains' performance to investigate a water seepage problem at a Botanic park in Kuala Lumpur, Malaysia. The simulation was carried out for transient conditions and successfully determined the cause of water seepage issue in the area.

Nabil (2016) [45] modelled the effluents from a steel industry that pollute the Meboudja River in Algeria. Groundwater flow and mass transport model were simulated using Visual MODFLOW.

Lee (2016) simulated the impacts of seasonal pumping on stream depletion. Visual MODFLOW was used to quantify stream aquifer interactions caused by the seasonal pumping of groundwater. Stream Depletion Factor (SDF) was found to be the reason for the seasonal variation of the stream depletion rate.

Park (2016) [49] undertook a feasibility study to determine the minimum embedded depth of vertical barrier to prevent possible contaminant leakage from an off-shore landfill. The study was successful.

Vijay (2016) [46] used modelling to assess the safe yield of groundwater withdrawal and quantified the future demand of water supply for the city of Puri, India, which is being subjected to constant sea water intrusion and continuous freshwater withdrawal due to pumping.

Steiakakis (2016) [47] studied the drought-induced impacts using Visual MODLFLOW. They investigated the combined effects of groundwater exploitation and climate variability on karst aquifers. Saline water intrusion was simulated using the SEAWAT package of the software. Suggestion to adjust the scheme of groundwater exploitation was recommended to prevent seawater intrusion.

10. Summary

Groundwater quality analysis along with the leachate characterization is needed to assess level of contaminant in the aquifer. The literature reviewed clearly shows that prediction of contaminant migration is the main factor in the assessment and administration of the dumpsite. Though different codes are available to predict the groundwater contamination, comprehensive representation of the area to be modeled is necessary to arrive at a meaningful solution for the issue of contaminant migration. The structural and non-structural measures are the necessary elements that have to be properly designed to prevent/reduce the contamination of leachate in the groundwater. Ample number of socio-economic issues are prevailing among the people residing adjacent to the dumpsite. Different variables are considered to measure the awareness on the usage of contaminated water. In the literature the respondents were selected based on the villages or places surrounding the dumpsite. The clear picture of the issues due to groundwater contamination can be summarized if the respondent were selected based on the groundwater quality and flow directions. Proper interlinking of technical output with the social issues is needed to frame a proper water management strategy in the contaminated area.

Reference

[1] Al Raisi SAH, Sulaiman H, Suliman FE, Abdallah O. Assessment of heavy metals in leachate of an unlined landfill in the Sultanate of Oman. Int J lEnviron Sci Dev. 2014;5(1):60.
[2] Hossain MK, Hossain ML, Das SR. Impact of Landfill Leachate on Surface and GroundWater Quality. J Environ Sci Technol. 2014;7(6):337–46. doi: 10.3923/jest.2014.337.346.
[3] Maiti SK, De S, Hazra T, Debsarkar A, Dutta A. Characterization of Leachate and Its Impact on Surface and Groundwater Quality of a Closed Dumpsite – A Case Study at Dhapa, Kolkata, India. Proc Environ Sci. 2016;35:391–9. doi: 10.1016/j.proenv.2016.07.019.
[4] Mishra H, Rathod M, Karmakar S, Kumar R. A framework for assessment and characterisation of municipal solid waste landfill leachate: an application to the Turbhe landfill, Navi Mumbai, India. Environ Monitor Assess. 2016;188(6) doi: 10.1007/s10661-016-5356-6.
[5] Abd El-Salam MM, I. Abu-Zuid G. Impact of landfill leachate on the groundwater quality: A case study in Egypt. J Adv Res. 2015;6(4):579– 86. doi: 10.1016/j.jare.2014.02.003.
[6] De S, Debnath B. Prevalence of Health Hazards Associated with Solid Waste Disposal- A Case Study of Kolkata, India. Proc Environ Sci. 2016;35:201–8. doi: 10.1016/j.proenv.2016.07.081.
[7] Gburek, W. J., and G. J. Folmar 1999 Flow and chemical contributions to streamflow in an upland watershed: a base flow survey Journal of Hydrology 217.1 1-18.

[8] Rao, VVS Gurunadha, R. L. Dhar, and K. Subrahmanyam 2001 Assessment of Contaminant Migration in Groundwater from an Industrial Development Area, Medak District, Andhra Pradesh, India Water, Air, and Soil Pollution 128.3-4 p369-389.

[9] Kuchling, Ken, D. Chorley, and W. Zawadzki.2000 "Hydrogeological modelling of mining operations at the Diavik Diamonds project." Proceedings of the Sixth International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production, University of Calgary, Calgary AB.

[10] Roadcap, George S., and Steven D. Wilson.2001 The impact of emergency pumpage at the Decatur wellfields on the Mahomet Aquifer: Model review and recommendations. Illinois State Water Survey.

[11] Chowdhury, Shafiul H., Alan E. Kehew, and Richard N. Passero.2003 "Correlation between nitrate contamination and ground water pollution potential." Ground water 41.6: p735-745.

[12] Jia, Jin-sheng, and Chang-ming Liu.2002 "Groundwater dynamic drift and response to different exploitation in the North China Plain: A case study of Luancheng County, Hebei Province." ACTA GEOGRAPHICA SINICA-CHINESE EDITION- 57.2 p 201-209.

[13] Meriano, Mandana, and Nick Eyles.2003 "Groundwater flow through Pleistocene glacial deposits in the rapidly urbanizing Rouge River–Highland Creek watershed, City of Scarborough, southern Ontario, Canada." Hydrogeology Journal 11.2 p 288-303.

[14] Tiwary, R. K., et al. 2005 "Assessment and prediction of contaminant migration in ground water from chromite waste dump." Environmental Geology 48.4-5 p 420-429.

[15] Hu, Yi, et al. 2006 "Visual Modflow and Its application problems in groundwater simulation." Journal of Nanhua University (Science and Technology) 2.

[16] WANG, Qing-yong, et al.2007 "Visual MODFLOW and its application to groundwater simulation [J]." Journal of Water Resources and Water Engineering p 25.

[17] Jyrkama, Mikko I., and Jon F. Sykes. 2007 "The impact of climate change on spatially varying groundwater recharge in the grand river watershed (Ontario)." Journal of Hydrology 338.3 p 237-250.

[18] Rejani, R., et al 2008. "Simulation modeling for efficient groundwater management in Balasore coastal basin, India." Water Resources Management 22.1 p23-50.

[19] Zume, Joseph, and Aondover Tarhule. 2008 "Simulating the impacts of groundwater pumping on stream–aquifer dynamics in semiarid northwestern Oklahoma, USA." Hydrogeology Journal 16(4) p 797-810.

[20] LIU, Yong-liang, and Guo-ying PAN.2009 "Mine inflow prediction and numerical simulation on descending flow field of Karst water based on Visual Modflow." Journal of Henan Polytechnic University (Natural Science) 1 p 015.

[21] YANG, Qiang, et al. 2009 "Application of Visual Modflow to Dewatering Design of Foundation Pit [J]." China Water & Wastewater 20 p 040.

[22] Mondal, N. C., and V. S. Singh. 2009 "Mass transport modeling of an industrial belt using visual MODFLOW and MODPATH: A case study." Journal of Geography and Regional Planning 2.1 p 1-019.

[23] Jovanovic, N. Z., et al. 2007 "Nitrogen dynamics in land cleared of alien vegetation (Acacia saligna) and impacts on groundwater at Riverlands Nature Reserve (Western Cape, South Africa)." Water SA 35.1 p 37-44.

[24] Shi, Weifang, Weihua Zeng, and Bin Chen. 2010"Application of Visual MODFLOW to assess the Sewage Plant accident pool leakage impact on groundwater in the Guanting Reservoir area of Beijing." Frontiers of Earth Science in China 4.3 p 320-325.

[25] Sarvarian, Mohammadreza, Mehdi Ghatei, and Masoomeh Lorestani. 2010"Finding Capture Zone and Sensitivity Analysis for Wells in Urmia Plain Based on Finite Difference Using Visual Modflow Software." 5th Civil Engineering Conference in the Asian Region and Australasian Structural Engineering Conference 2010, The. Engineers Australia.

[26] Feng, Juan, Guan Qun Liu, and Quan Sheng Zhao. 2010"Application of Visual MODFLOW to the dynamic change and simulation of deep groundwater in Dezhou City, China." Advanced Materials Research. Vol. 113. Trans Tech Publications.

[27] Saravanan, R., et al. 2011 "Groundwater modeling and demarcation of groundwater protection zones for Tirupur Basin–A case study." Journal of Hydro-environment Research 5.3 : p197- 212.

[28] Faghihi, Neda, Fereydoon Kave, and Hossein Babazadeh. 2011 "Prediction of Aquifer Reaction to Different Hydrological and Management Scenarios Using Visual MODFLOW Model, Case Study of Qazvin Plain." Journal of Water Sciences Research p12.

[29] CHEN, Jianhong, et al. 2011"Water inflow forecast of bauxite mine based on visual modflow and grey theory." Mineral Engineering Research p 012.

[30] Saghravani, Seyed Reza, et al. "Phosphorus Migration in an Unconfined Aquifer Using Modflow and Mt3dms." Journal of Environmental Engineering and Landscape Management 19.4 (2011): 271-277.

[31] Rao, G. Tamma, et al. "Assessment of groundwater contamination from a hazardous dump site in Ranipet, Tamil Nadu, India." Hydrogeology Journal19.8 (2011): 1587-1598.

[32] Faghihi, Neda, Fereydoon Kave, and Hossein Babazadeh. "Prediction of Aquifer Reaction to Different Hydrological and Management Scenarios Using Visual MODFLOW Model, Case Study of Qazvin Plain." Journal of Water Sciences Research 2.1 (2011).

[33] Parameswari, K., B. V. Mudgal, and Prakash Nelliyat. "Evaluation of groundwater contamination and its impact: an interdisciplinary approach." Environment, development and sustainability 14.5 (2012): 725-744.

[34] Varalakshmi, V., et al. "Groundwater flow modeling of a hard rock aquifer: case study." Journal of Hydrologic Engineering 19.5 (2012): 877-886.

[35] Liolios, Konstantinos A., Konstantinos N. Moutsopoulos, and Vassilios A. Tsihrintzis. "Modeling of flow and BOD fate in horizontal subsurface flow constructed wetlands." Chemical engineering journal 200 (2012): 681-693.

[36] Qi-peng, SHi, et al. "Application of Visual Modflow to Simulate Groundwater Contamination Migration [J]." Yellow River 12 (2012): 027.

[37] Al, M., et al. "Hydrogeological condition and assessment of groundwater resource using visual modflow modeling, Rajshahi city aquifer, Bangladesh." Journal of the Geological Society of India 79.1 (2012): 77.

[38] Wang, Hong, et al. "Modeling the impact of soil and water conservation on surface and ground water based on the SCS and Visual Modflow." PloS one8.11 (2013): e79103.

[39] Beltrán, Guillermina Gómez, et al. "Application of the Visual Modflow Model for the Evaluation of the Hydrodynamics of Underlying Aquifer to an Urban Solid Waste Sinter." International Journal of Environmental Pollution 29 (2013): 119-126.

[40] Kant, Shri, et al. "Modeling of Groundwater Levels in the Sonar sub-basin, Madhya Pradesh Using Visual MODFLOW." Indian Journal of Dryland Agricultural Research and Development 28.1 (2013): 33-37.

[41] Yamindinda, Lugendo Prudence. Economic viability and economic impact of Mkindo irrigation scheme in Mvomero district, Tanzania. Diss. Sokoine University of Agriculture, 2013.

[42] Surinaidu, L., et al. "Application of MODFLOW for groundwater Seepage Problems in the Subsurface Tunnels." J. Ind. Geophys. Union (October 2015) 19.4: 422-432.

[43] Rao, G. Tamma, et al. "Application of numerical modeling for groundwater flow and contaminant transport analysis in the basaltic terrain, Bagalkot, India." Arabian Journal of Geosciences 6.6 (2013): 1819-1833.

[44] Rajamanickam, R. "Groundwater quality modeling of Amaravathi river basin of Karur district, Tamil nadu, using visual Modflow." (2013).

[45] Kumar, GN Pradeep, and P. Anil Kumar. "Development of Groundwater Flow Model Using Visual MODFLOW." International Journal 2.6 (2014): 649-656.

[46] Zhai, Xiaorong, et al. "Drainage Evaluation of Limestone Aquifer Based on Visual Modflow." (2014). [41] Parameswari, K., and B. V. Mudgal. "Assessment of contaminant migration in an unconfined aquifer around an open dumping yard: Perungudi a case study." Environmental Earth Sciences 74.7 (2015): 6111-6122.

[47] Varghese, Anju Anne, Rajkumar V. Raikar, and B. K. Purandara. "Simulation of Groundwater Levels in Malaprabha Command Area using Visual MODFLOW FLEX." (2015).

[48] Qadir, Anwar, et al. "A spatio-temporal three-dimensional conceptualization and simulation of Dera Ismail Khan alluvial aquifer in visual MODFLOW: a case study from Pakistan." Arabian Journal of Geosciences 9.2 (2016): 1-9.

[49] Persson, Joakim, and Niklas Andersson. "Modeling groundwater flow and PFOS transport: A case study at the old fire drill site of Bromma Stockholm Airport." (2016).

[50] Sauvage, Sabine, and José-Miguel Sánchez-Pérez. "Modelling of ground water contamination, plants case of El Hadjar, N East of Algeria." iEMSs 2016 Conference. Vol. 5. 2016.

[51] Vijay, Ritesh, and P. K. Mohapatra. "Hydrodynamic assessment of coastal aquifer against saltwater intrusion for city water supply of Puri, India." Environmental Earth Sciences 75.7 (2016): 1-8.
[52] Steiakakis, E., et al. "Drought impacts on the fresh water potential of a karst aquifer in Crete, Greece." Environmental Earth Sciences 75.6 (2016): 1-19.
[53] Baharuddin, M. F. T., et al. "Simulation of Sub-Drains Performance Using Visual MODFLOW for Slope Water Seepage Problem." IOP Conference Series: Materials Science and Engineering. Vol. 136. No. 1. IOP Publishing, 2016.
[54] Park, Haeyong, Myounghak Oh, and Osoon Kwon. "Analysis on Contaminant Transport according to the Embedded Depth of Vertical Barrier of Offshore Landfill." Journal of the Korean Geoenvironmental Society 17.8 (2016): 29-37.
[55] Li, Xiaolong, et al. "Study on groundwater using visual MODFLOW in the Manas River Basin, China." Water Policy (2016): wp2016180.