Review

Environment

A Narrative Review of Groundwater and Soil Pollution

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In accordance with the migration and transformation laws of pollutants in soil and groundwater, the research progress of chemical fertilizers, pesticides, and sewage irrigation is reviewed systematically from three perspectives: the topsoil layer, the underground aquifer, and the unsaturated zone. The results of the study of migration and transformation in various water layers and unsaturated soils illuminate the current research's problems and future directions.

Keywords: Groundwater; Water Contamination; Topsoil; Aquifer; Unsaturated Zone; Contaminants; Migration and Transformation

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THE water and soil system are the fundamental structural units of the biosphere and the indispensable material foundation for human society. However, as a result of the rapid development of social production and the continuous growth of the human population, the biosphere is being severely degraded, and resources are becoming scarce (1). As far as human demand for water resources is concerned, the rapid development of industrial and agricultural production as well as the continuous improvement of people's living standards has led to an increase in the quantity and quality of water required by them. However, more and more solid, gaseous, and liquid wastes are generated, resulting in increasingly severe surface and groundwater contamination (2). So far, the degree of water pollution has reached a critical level.

In recent years, the emphasis of groundwater research and investigation in industrialized nations has shifted from groundwater supply to groundwater quality. As a result of human production and existence, the groundwater environment is increasingly impacted by pollution. There is threat to groundwater posed by industrial waste residues, chemical fertilizers and pesticides, or municipal solid waste (3). Therefore, extensive research has been conducted domestically and internationally.

Soil and Groundwater Pollution

In the 1970s, humans began to fully comprehend and investigate the law governing the migration and transformation of pollutants in soil and groundwater (4). According to the migration pathways of pollutants in soil and groundwater systems, previous research has been conducted from three vantage points: the topsoil layer, the aquifer, and the unsaturated zone, and a number of results have been obtained.

Migration and Transformation of Contaminants in Topsoil

According to the various characteristics of pollutants, surface soil pollution can be categorized as follows (5): (i) Pollution from inorganic waste (heavy metals and salts); (ii) Pollution from organic waste (including biodegradable and biorefractory substances); (iii) Pollution from fertilizers; (iv) Pollution from pesticides (including pesticides, fungicides, and herbicides); (v)

Pollution from sludge, slag, and fly ash; (vi) Pollution from radioactive substances; (vii) Pollution from parasites, pathogenic bacteria, and viruses. Agronomists have placed a high value on the pollution caused by heavy metals and organic pesticides, which has been the subject of extensive research conducted. Research has made significant advances. Due to the diversity of the soil sphere, the wide variety of pollution sources and methods, as well as the different mechanisms of interaction between pollutants and various environmental components (6). Therefore, almost every specific object must be studied individually.

Contaminated Irrigation and Soil

Numerous pollutants undergo complex physical, chemical, and biological transformations as a result of the presence of a significant amount of organic matter in the topsoil. Considering the thin topsoil layer, the black-box model is frequently employed to describe the migration and transformation of pollutants (7); however, there are few studies on the internal mechanism. In recent years, scholars in environmental soil science have utilized model tests to determine the environmental capacity of soils (8).

Soil Contamination Resulting from Agricultural Modernization

In the process of agricultural modernization, the widespread use of chemical fertilizers and pesticides has emerged as the most significant contributor to soil pollution (9). Among them, eutrophication of water bodies caused by excessive nitrogen and phosphorus pollution and the problem of nitrate pollution of groundwater are the most prominent (10, 11). To increase grain yield, the agricultural sector has conducted extensive research on the optimal application time and number of chemical fertilizers for crop growth, but relatively little research has been conducted on the downward migration of chemical fertilizers and pesticide pollutants and their effect on groundwater. In recent years, a high priority has been placed on the issue of environmental pollution caused by pesticides, continually phasing out environmentally hazardous pesticides and gradually promoting low-toxicity, harmless, or biological pesticides (12).

Migration and Transformation of Groundwater Contaminants

The majority of research on the migration and transformation of pollutants in groundwater employs mathematical simulation techniques. When using mathematical models to simulate the migration of soluble pollutants in underground aquifers, it is necessary to obtain the temporal and spatial variation of the concentration in order to predict the instantaneous dynamics and expansion range of groundwater pollution, as well as to select the optimal treatment plan in order to develop reasonable and effective groundwater pollution prevention and control measures (13). The groundwater quality model is the mathematical model established by simulation research on groundwater quality (14).

Mathematical models have been being developed to investigate groundwater problems, but it was not until the 1960s that mathematical models were applied to groundwater quality simulation research. The former Soviet Union's Bear and Bachmat completed a comprehensive review of the study of hydrodynamic dispersion in porous media in 1967 (15). On the basis of simplified and statistical models, they discussed various hydrodynamic dispersion theories, the formation of boundaries and initial conditions, the theory of the relationship between dispersion coefficients and water velocity and the geometry of infiltrating media, and provided measured data, highlighting in particular that water dispersion coefficients are inversely proportional to water velocity. The longitudinal and transverse dispersion coefficients can be used to characterize the dynamic dispersion. Since then, investigations on the molecular diffusion problems were carried out for analytical solutions of increasingly complex computational schemas, such as two-dimensional dispersion, gravitational differentiation, and the interaction of migrating substances with media and groundwater. In 1972, additional research was conducted on the classical model and the hydrodynamic dispersion equation. The premise of this equation is the continuity of macroscopic porous media and proposed a new hydrodynamic dispersion model considering the jump changes of concentration and concentration gradient at the interface of solid matter and pores (16), which resulted in the addition of a supplementary term to the hydrodynamic dispersion equation. A sophisticated mathematical model was developed for predicting contaminant concentrations in aquifers (17). Gorelick and Remson presented a general model for the dynamic management of groundwater quality within a dispersed parameter system (18).

1978 Report presented by the United States Geological Survey on a model of groundwater quality resolved steady-state flow and transient flow issues by simultaneously solving the groundwater flow equation and concentration equation (19). Theoretical and experimental research of groundwater solute transport has advanced. A space-time-related expression is proposed for the dispersion coefficient of pollutant migration. Experimental studies have made the coefficients of the decay, ion exchange, biological and chemical reaction terms in the migration equation more reasonable, and the factors considered are broader (20). From the equilibrium isothermal mode to the non-equilibrium adsorption mode, the mutual conversion relationship between solid and liquid concentrations of pollutants and adsorption conditions was derived. Particularly in the setting of initial and boundary conditions, it tends to be more reasonable and exhaustive (21). The analytical solution of the one-dimensional model of the transport and transformation of pollutants in groundwater has reached new heights. In light of the complexity and variability of groundwater data monitoring, stochastic models for pollutant migration and transformation have been intensively studied (22). Regarding the water movement of the migration carrier, it has been designed to consider both movable and immovable water bodies.

Status Quo of the Migration and Transformation of Contaminants in Unsaturated Soil

Much less research has been conducted on the migration and transformation of pollutants in unsaturated soil (vadose zone) than on topsoil and aquifer. Due to the influence of industry and research, soil disciplines and agricultural departments primarily examine, from the perspective of crop growth, the impact of pollutants on crops and soil structure in the topsoil layer, while ignoring the downward migration of pollutants. However, gen-

eral hydrogeologists tend to focus on the migration and transformation of contaminants in subterranean aquifers (23). As for the migration and transformation of pollutants in the unsaturated zone, it has been neglected for a considerable amount of time, which is the reason why many studies on groundwater pollution cannot be conducted in depth and the pollution cannot be controlled. In recent years, scholars have begun to investigate the migration and transformation of pollutants in the unsaturated zone; this positive trend will undoubtedly encourage the in-depth study of groundwater pollution. Obviously, this will add new challenges to the already challenging research work.

The migration and transformation of pollutants in unsaturated soil was regarded as a significant topic in the study of groundwater contamination. The vertical one-dimensional dispersion coefficient and attenuation coefficient of the unsaturated zone have been determined through a large number of soil column tests conducted indoors and outdoors (24). The majority of tracers are salts or substances with a low reactivity. Since then, the migration and transformation of heavy metals in the unsaturated zone has been gradually studied, the distribution coefficients of soil liquid and solid concentrations are considered, and the liquid phase is represented by the Henry, Freundlich, and Langmuir isotherm adsorption model (25). Currently, the relationship between the adsorption and desorption of solid phase concentration and the non-equilibrium adsorption and desorption problem is being investigated. Regarding the dispersion coefficient, coefficient was extended to a time- and space-varying dynamic parameter (26). In terms of soil water movement, the study progressed from the average pore velocity of the unsaturated zone to the study of movable and immovable water bodies, as well as the interaction between water, air, pollutants, and soil. The solution to the mathematical model is also continuously evolving, from a simple analytical solution of the unsaturated zone to a numerical solution of complex factors, and the initial and boundary conditions of the solution are also continuously improved, bringing them closer to the actual situation of pollutant migration.

In the research on the migration and transformation of pollutants in unsaturated soils, numerous valuable experimental data and theoretical analysis results have been obtained, laying the groundwork for future studies. In general, however, the current research is still in its preliminary stages, and the following issues require further investigation: (i) The mechanism of migration and transformation of pollutants in unsaturated soil has not yet been understood, and both laboratory and field tests have been conducted, whereas there are still numerous flaws; (ii) there is no mature predictive model that can be applied more effectively; (iii) the parameter calibration method and value have not been clarified; (iv) it is the most hazardous to non-conservative pollutants, especially groundwater; and (v) it is the least beneficial to the environment.

Issues with the Research

Throughout the current study on soil and groundwater pollution, the following aspects are notably lacking:

i. Existing models are too ideal to be measured from an application standpoint, and it is impossible to achieve application criteria for precision.
ii. For experimental and theoretical study on the movement and transformation of contaminants in the unsaturated zone is still in its infancy.
iii. In unit-level models, research is conducted There are numerous models, but few that are applicable.
iv. In models that account for the migration and transformation of pollutants, there are several unit-level models but few global models.
v. The majority of the pot studies on the topsoil layer are static, and the relationship between pollution content and plant development is rarely examined, as is the downward migration of pollutants.
vi. In experimental research, the total physical model is too tiny, and the soil column experiments conducted to date are not typical due to their small scale.
vii. Many empirical parameters and mechanistic elements of pollution movement and transformation are considered in the applicable models. Exceptions include the black box model of the topsoil layer.
viii. There are more deterministic models and less random ones.
ix. The model for the transport and transformation of contaminants in aquifers is overly reliant on measurable data and difficult to implement.
x. In the current theoretical analysis and experimental data, there are more studies on conservative pollutants than on non-conservative pollutants.

Perspectives

The following are the primary research trends regarding the migration and transformation of pollutants in soil and groundwater: (i) Establish a forecast model suitable for groundwater environmental assessment and analysis based on the mechanism of pollutant migration and transformation; (ii) Concentrate on enhancing research on the mechanism of migration and transformation in unsaturated zones, focusing specifically on It is a study of the mechanism of migration and transformation of compound pollutants; (iii) Evaluate the impact of non-point source pollutants on groundwater, such as fertilizers, pesticides, and sewage irrigation, and implement technical controls; (iv) Method of stage parameter calibration; (v) The three-dimensional mathematical model-solving technique and numerical simulation technology for analyzing the infiltration of point source pollutants; (vi) Studies on the stochastic model of pollutant migration and transformation in soil and groundwater, as well as the impact of groundwater resources (water quality and quantity); (vii) to investigate the variation law of model parameter variations under different conditions.■

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