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Application of Soil's Self-Decontamination Ability to Contaminated Ground

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흙의 자체정화능력을 이용한 오염된 토양정화

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Abstract

There are numerous approaches available to cleanup a contaminated surface and subsurface ground currently in use, however, these methods all classify the decontamination after the contamination has penetrated into the soil masses and is costly. Unlike these approaches, in this study, utilization of soil's self-decontamination ability by rearranging and preplanning of the topographical features and surface and subsurface drainage systems for the potential contamination sites before or during contamination process has been considered as an another cleanup method. Step by step explanations on why and how to develop the self-decontamination procedure is proposed in detail. Two examples are presented including contaminated saltwater intrusion along a coastal region and control or prevention of radioactive toxic radon gas (^{222}Rn) in residential areas. The effectiveness of the proposed systems to these two examples using the soil's self-decontamination ability is well illustrated.

keywords : Contamination process, Self-decontamination, Soil, Surface and subsurface drainage

1. Introduction

Hazardous and toxic waste cleanup processes are a major task of the overall environmental problems related to ground pollution. There are numerous approaches available to cleanup these wastes currently in use, however, these methods all classify the decontamination after the contamination has penetrated into the soil masses (Hunt et al., 1988; Johnson et al., 1990; Kovalick et al., 1996; Sabatini et al., 1995; Sims et al., 1986). Soils can be easily contaminated but very difficult to decontaminate, because the mechanisms of contamination and decontamination processes are different and the process is not reversible. The contamination process is simple, however, the decontamination mechanism is much more complicated than the contaminated process, and also costly. Because of this reason, a concept for soil's self-decontamination system is proposed. The proposed procedures are based on three basic steps as :

(a) utilization of soil's own decontamination ability to absorb and/or neutralize some pollution substances prior and the during the contaminating stage;
(b) prevent and/or control the amount of the incoming liquid pollution to a level of soil's own digestion process; and
(c) control the surrounding topographical features prearranging both surface and subsurface drainage systems or networks to let some liquid pollution go away before it intrudes into the soil layer.

In this paper, three parts are presented: (1) close examination of the mechanism of a decontamination system, explaining why and how it is more complex than a contamination mechanism; (2) presenting the information on soil adsorption and soil's own pollutant digest-ability, and (3) two examples including a control for contaminated saltwater intrusion along a coastal region and another one is controlling or preventing radioactive toxic radon gas (^{222}Rn) in residential area used to illustrate the effectiveness of this proposed soil self-decontamination

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system. It is hoped this system may reduce hazardous toxic waste cleanup cost.

2. Characteristics of Soil Contamination and Decontamination Processes

Regardless of the types of pollution and pollution intrusion routes, three basic soil characteristics of soil contamination and decontamination processes must be examined: (a) the contamination potential of the soil; (b) minimum requirement of the contamination and decontamination pressures (or forces) of the soil in the environments; and (c) soil structure system.

(1) *Soil Contamination Potential* : Soil contamination potential depends upon such factors as: (a) soil particle size and its surface area, the smaller the soil particle, the larger the surface area per volume and the higher chance to be contaminated. This means that the clay-like soil has more contamination potential than sandy soil; (b) low bonding strength between soil particles. Lower bonding strength makes it easy for soil particles to be separated from each other, the higher the potential to be contaminated; and (c) the higher the ion exchange capacity (IEC) of soil, the easier for soil to interact with environments, consequently for soil to be contaminated. For example, montmorillonite clay has a higher contamination potential than kaolinite clay because montmorillonite clay has a smaller particle size, low bonding strength and higher IEC than kaolinite clay.

(2) *Contamination Pressure (Adsorption Pressure)* : Soil's contamination pressure (or force) mainly is the soil's adsorption pressure. Adsorption processes include both physical and physicochemical processes. It is defined as the concentration of a substance on a surface. It is the uniform penetration of molecules of one phase in between the molecules of a second phase. All solids or mineral particles tend to adsorb gases and solutes with which they are in contact. As indicated in a previous statement, the fine-grained soil has more adsorption capacity than larger soil particles. In general, the amount of adsorption depends on the nature of the adsorbent, the nature of the substance being adsorbed, the surface area of the adsorbent, the temperature, and the pressure in the soil-water system.

(3) *Intensity of Contamination Pressure* : A schematic diagram illustrates the intensity of contaminated pressure (adsorption pressure) around the soil particle surface at point **A** is shown in Fig. 1(a). In examining Fig. 1(a), the

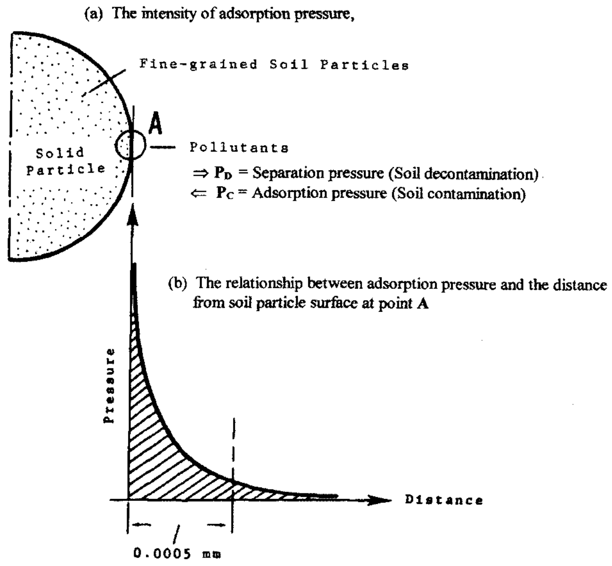

Fig. 1. A Schematic diagram illustrates soil contamination relating to adsorption pressure around the soil particles: (a) The intensity of adsorption pressure, and (b) Adsorption pressure vs. distance from soil particle.

adsorption pressure is high and varied depending on the environmental conditions at point **A**. Blanck (1938) reported that pressure is about 50 kg/cm^2 at hygroscopicity moisture content condition; 6.25 to 12.5 kg/cm^2 at wilting point. Winterkorn (1955) claimed that pressure could be reached as high as 25,000 psi (172,500 kPa) in humid climates. The relationship of adsorption pressure and distance from point **A** is indicated in Fig. 1(b). Further away from point **A**, the less the intensity contaminated pressure will be like the relationship of potential and distance from the mineral surface (Holtz et al., 1981).

(4) *Decontamination Pressure (Separation Pressure)* : The intensity of contamination pressure is high as discussed (50 kg/cm^2 at hygroscopicity moisture content condition; 6.25 to 12.5 kg/cm^2 at wilting point found by Blanck (1938) and 25,000 psi (172,500 kPa) in humid climates found by Winterkorn (1955). The decontamination pressure (separation pressure) should be greater than contaminated pressure in order for a soil to be decontaminated. The adsorption pressure is pressure caused by a soil contamination, and the separation pressure is the pressure to perform the decontamination. Adsorption pressures vary with local environments. As indicated in Fig. 1 which is a diagram illustrating the soil contamination relating to adsorption pressure around the soil particles, adsorption pressure, P_C (soil contamination) and separation pressure, P_D (soil decontamination) is different and adsorption pressure (P_C) is greater than the separation pressure (P_D) at point **A** and P_C is lower than P_D in surround the soil particle.

(5) *Soil Structure System* : The soil structure also indicated that flocculated structure (face-to-edge) contains more pollutants than dispersive structure (face-to-face), because flocculated type of mineral structure has more voids (Fig. 2).

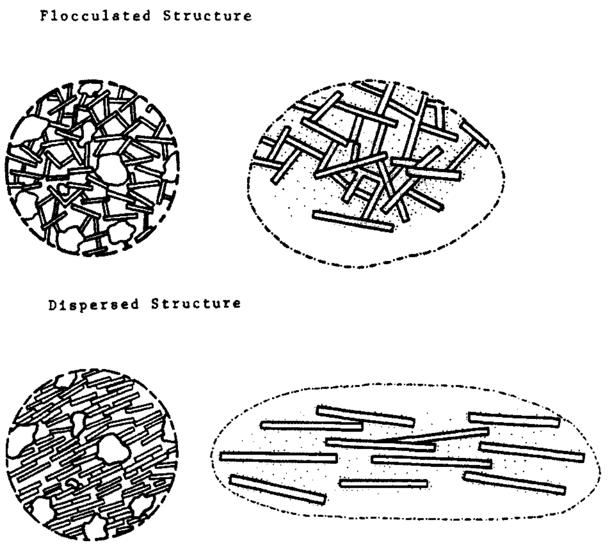

Fig. 2. Mineral structures relating to the degree of contamination: (a) Flocculated structure; and (b) Dispersed structure (From Collins et al., 1974).

3. The Concept of Soil Self - Decontamination Processes

3.1. General Discussion

Ecosystems and environmental cycles in nature generally are in an equilibrium condition. Also, soil-water in nature has self-decontamination ability. This so-called self-decontamination ability includes: sedimentation, neutralization, evaporation, infiltration, and absorption. Table 1 presents the soil types of self-decontamination processes. In examining Table 1, the types of soil self-decontamination processes include mechanical, physical, physicochemical, and chemical processes and Table 2 is a summary of factors for soil self-decontamination. If pollution intrusion is less than soil's self-decontamination ability, at indicates that soil has less potential to be contaminated.

3.2. Factors Affecting Soil Self - Decontamination Process

There are numerous factors affecting soil self-decontamination process including atmosphere, biosphere, lithosphere, hydrosphere and geomicrobiosphere are summarized in Table 2. Equation 1 illustrates if soil self-decontamination ability, (S_a) is greater than pollution intrusion potential (P_i), then this soil layer has higher self-decontamination ability. Further discussion will be illustrated in ***Example 1***.

Table 1. Types of soil self-decontamination processes

[1] *Mechanical-physical Processes*
(a) Evaporation, Evapotranspiration,
(b) Infiltration,
(c) Sedimentation, and
(d) Absorption process.
[2] *Physicochemical and Chemical Processes*
(a) Neutralization,
(b) Ion exchange reaction,
(c) Adsorption process, and
(d) Redox reaction.

Table 2. Factors affects of the soil self-decontamination process

[1] *Atmosphere*
Some pollutants blow away by wind or wash away by rainstorm
[2] *Biosphere*
Interaction with tree and vegetation,
Land surface runoff; Evaporation,
Evapotranspiration; and Percolation to subsurface layer.
[3] *Lithosphere*
Sorption (absorption and adsorption)
[4] *Hydrosphere*
Pollutants neutralized with other ions in water
[5] *Geomicrobiosphere*
Some pollutants eaten by bacteria;
Absorbed by tree roots; and
Absorbed by vegetation as part of fertilizer.

$$S_a > P_i \tag{1}$$

where S_a = soil self decontamination ability; and P_i = pollution intrusion potential.

3.3. Soil's Self-Digesting (Self-Decontamination) Ability

As discussed in Section 2 and Fig. 1, indications are that soil's contamination is mainly caused by adsorption pressure. However, adsorption pressure also can be applied to the soil is self digesting ability (soil's decontamination ability). Adsorption is part of a sorption process and is an important process in the soil contamination and decontamination systems. Further discussion together with additional experimental data is presented in Table 3 and Fig. 3. Sorption processes include both absorption and adsorption processes. Absorption is a mechanical energy similar to the saturation commonly used in soil mechanics. Adsorption is a physicochemical multimedia energy process. In dealing with soil contamination, adsorption is more important than absorption.

(1) *Adsorption* : Adsorption process is also a major characteristic for the self -decontamination system. There are two types of adsorption processes, the physical and

physicochemical processes. In nature, clay minerals have adsorption ability as indicated in Table 3 (Wang, 1985; Fang, 1997). In examining Table 3, mixtures of soil types of with various particle sizes and shapes have larger the adsorption ability. According to the particle packing theory (Lambe et al., 1986), a denser particle packing pattern having lesser voids between particles, consequently, will give less adsorption ability.

Table 3. Clay mineral and soil adsorption ability

Mineral or soil types	Adsorption, %
[1] *Minerals*	
(a) Illite	10.5
(b) Kaolinite	34.5
(c) Montmorillonite	11.0
(d) Mixtures	64.0
[2] *Soils*	
(a) Clay	See Fig. 3(a)
(b) Loess	See Fig. 3(b)

(2) *Effect on Particle Size and Shape* : Adsorption Related to Soil Particle Size and Shape : Fig. 3(a) presents adsorption versus soil particle size. The smaller the soil particle, the more soil can be absorbed. Fig. 3(a) shows adsorption with hazardous substance phenol versus substance particle size, the smaller the particle size, greater the adsorption potential.

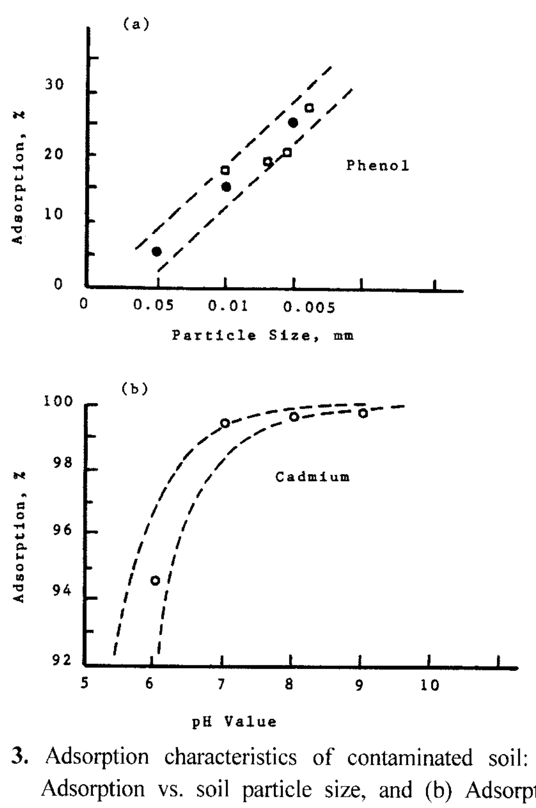

Fig. 3. Adsorption characteristics of contaminated soil: (a) Adsorption vs. soil particle size, and (b) Adsorption vs. contaminated pore fluid (From Wang, 1985).

(3) *Effect on Pore Fluid* : Sorption related to contaminated pore fluid is reflected by pH value for cadmium (Cd) as indicated in Fig. 3(b). With limited data shown in Fig. 3(b), the higher the pH value (basic solution), the greater the adsorption. Recently, it is also indicated that for a given soil, lower pH value (acid) will give higher adsorption.

3.4. Sedimentation and Neutralization

(1) *Sedimentation* : Sedimentation is defined as suspensions or dust particle in water. The range of suspension varies from 10^{-2} mm to 10^{-6} mm. Suspensions or dust particles carry various types of bacterial, and/or contaminated elements. Sedimentation process is that soil particles can settle by their own weight.

(2) *Neutralization* : Certain substances neutralize with other substances becoming harmless substances

4. Examples Illustrate Soil Self-Decontamination Processes

4.1. General Discussion

There are two general approaches for the soil self-decontamination processes namely : (a) decontamination by controlling input and output pollutants as illustrated by Eq. 1, and (b) decontamination by controlling the topographical features letting contamination liquid waste go away through surface and subsurface systems or networks. Two examples are presented herein.

Example 1 illustrates controlling the contaminated saltwater intrusion by controlling the input and the output energies.

Example 2 illustrates control or prevention of radioactive toxic radon gas in residential area by controlling the surface and subsurface drainage systems or networks showing the effectiveness of soil self-decontamination processes.

4.2. Controlling Input and Output Pollutants

Equation 1 stated that soil's self-decontamination ability (S_a) is greater than pollution intrusion (P_i), then it can be said that the soil is free of contamination. On the principal, if the input energy is greater than output energy, then there is no incoming contamination. Following is an example based on controlling input and output energies (pollutants).

4.2.1. Problems of Contaminated Saltwater Intrusion

Saltwater intrusion is coastal shoreward movement of saltwater from ocean into coastal aquifers due to the over pumping of groundwater, consequently leading to the pollution possibility of groundwater aquifers, drinking wells and corroding subsurface structures, such as pile foundations, sheet piling, caissons, etc. Freshwater and saltwater are treated as two immiscible fluids, separated by an interface with a slope as indicated in Fig. 5(b). This interface can be estimated by theoretical or experimental methods. The following approach (Figs. 4 & 5a) illustrates allowing input energy such as rainfall and percolation to balance out with groundwater pumping and to make sure that the freshwater-saltwater interface remain constant.

Input Energy		**Output Energy**
Net rainwater		*Pumping Wells*
⇓		No. of Wells
Percolation		Depth, Size
⇓		Amount of Water Pumped
Groundwater Recharge	≈ ⇒	Amount of Water Used

Fig. 4. Input energy vs output energy.

4.2.2. *Example 1* : Controlling Saltwater Interface

Using saltwater intrusion process as illustrated in Figs. 5(a) and 5(b) as an example, if the amount of rainwater (input energy) percolates into the ground is equal or greater than groundwater pumped out from pumping wells (output energy) (Fig. 5(a)), then the saltwater-fresh water interface line shown in Fig. 5(b) will remain constant at all the time. This means that groundwater will not be polluted by saltwater even though, the pumping well is still in operation. A laboratory model study using a vertical viscous flow model illustrates such coastal saltwater pollution problems. Detailed test procedure given by Fang et al. (1976).

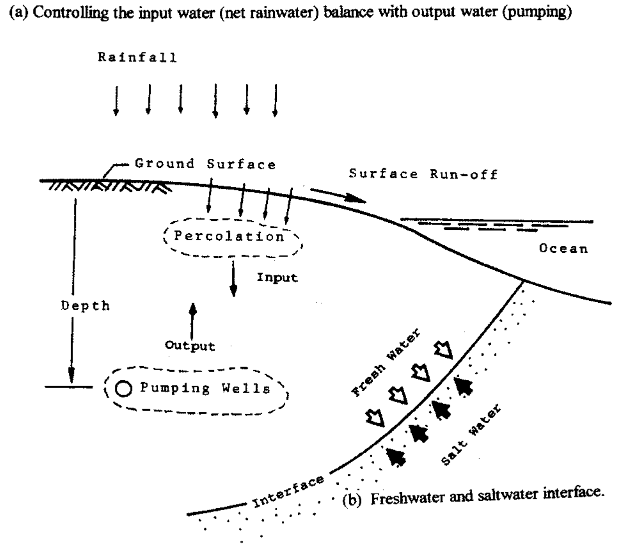

Fig. 5. A schematic diagram illustrates controlling contaminated saltwater intrusion: (a) Controlling the input water (rainfall) balanced with output (pumping), and (b) Freshwater and saltwater interface.

4.3. Controlling Topographical Features and/or Drainage Systems

4.3.1. Problems of Radioactive and Toxic Radon Gas

Radioactive and toxic radon gas (Rn) is produced naturally in the ground by the normal decay of uranium (U) and radium (Ra), and widely distributed in trace amounts in the Earth's crust. It is colorless, odorless and tasteless. It does not burn or glow and is undetectable by human senses. Radon gas itself is not an immediate concern to human health. However, if radon continues to undergo radioactive decay, it produces new naturally radioactive materials. These new materials, which are solid and not gaseous can stick to surfaces, such as dust particles in the air, and thereby. These contaminated dust particles can be inhaled and deposited on the surface of the lungs, human or animal. Also, it can collect on trees, flowers or vegetation, and becomes part of the pollution cycle in or day-to-day environment.

Based on research findings (DER, 1985; Fang, 1989, 1990, 2002; Fang et al., 1987), indications are that radon gas (Rn) is closely associated with water molecules. Therefore, for controlling the radon gas, control the topographical features and/or drainage systems. Prior potential liquid pollution intrusion, the potential pollution can be controlled by controlling the nearby or surrounding topographical features of the land and/or arrange and preplan the local surface and subsurface drainage systems or networks. The main purpose is to division channel away the potential liquid contaminated waste. Following is an example to remove radioactive toxic radon gas.

4.3.2. *Example 2* : Decontamination of Radioactive/Toxic Radon Gas

As discussed in a previous section, it can be concluded that: radon gas exists in rock, mineral, soil, water and air; and radon gas is very closely related with water. Therefore, we can use a conventional dewatering process and can remove the radioactive toxic radon gas in residential areas as illustrated in Figs. 6(a), 6(b), 7(a) and 7(b). In examining Fig. 6, radon gas can be removed by controlling both surface and subsurface drainage systems, Fig. 7(a) that radon gas can be remove by installation of

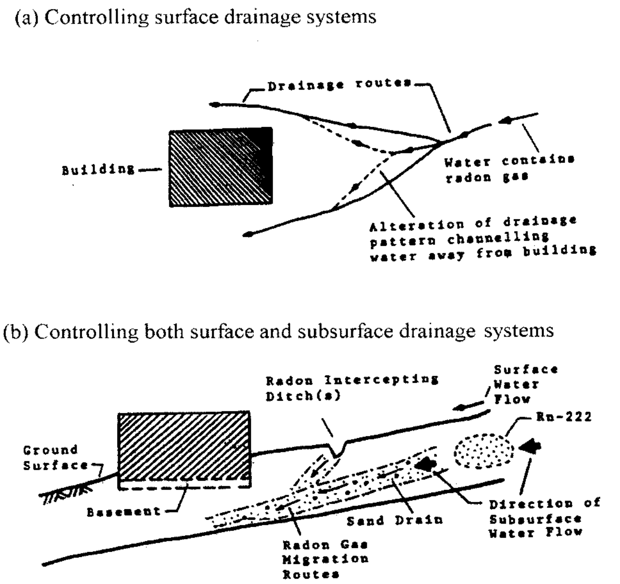

Fig. 6. Toxic radon gas controlling surface and subsurface drainage systems: (a) Controlling surface drainage system; and (b) Controlling both surface and subsurface drainage systems.

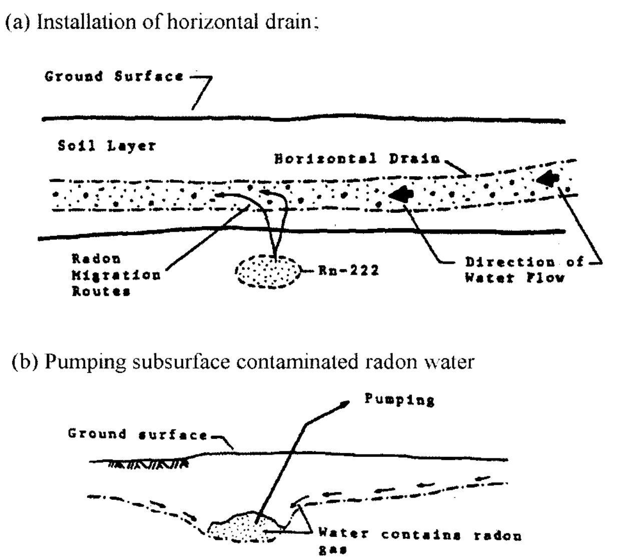

Fig. 7. Toxic radon gas controlling systems: (a) Installation of horizontal drain; and (b) Pumping subsurface contaminated radon water.

horizontal drain, and Fig. 7(b) by pumping the subsurface contaminated water.

5. Conclusions

This study was carried out to find out the utilization of soil's self-decontamination ability to cleanup the contaminated ground. To accomplish this, the concept of soil's self-decontamination was introduced in detail and its application systems were examined as examples. The following conclusions can be drawn.

(1) Soils can be easily contaminated but very difficult to decontaminate, because the mechanisms of contamination and decontamination processes are different and the process is not reversible. In addition, the contamination process is simple, however, the decontamination mechanism is much more complicated than the contaminated process.

(2) Soil-water in nature has self-decontamination ability. This so-called self-decontamination ability includes: sedimentation, neutralization, evaporation, infiltration, and absorption. There are numerous factors affecting soil self-decontamination process including atmosphere, biosphere, lithosphere, hydrosphere and geomicrobiosphere.

(3) If the input energy is greater than output energy, then there is no incoming contamination. Saltwater intrusion is coastal shoreward movement of saltwater from ocean into coastal aquifers due to the over output energy such as pumping of groundwater, consequently leading to the pollution possibility of groundwater aquifers, drinking wells and corroding subsurface structures. If the amount of rainwater (input energy) percolates into the ground is equal or greater than groundwater pumped out from pumping wells (output energy), then the saltwater-fresh water interface line will remain constant at all the time and groundwater will not be polluted by saltwater.

(4) Prior potential liquid pollution intrusion, the potential pollution can be controlled by controlling the nearby or surrounding topographical features of the land and/or arrange and preplan the local surface and subsurface drainage systems or networks. Radon gas exists in rock, mineral, soil, water and air is very closely related with water. Conventional dewatering process can remove the radioactive toxic radon gas in residential areas.

국문요약

최근에 오염된 토양을 정화하기 위해서 다양한 방법들이 사용되고 있으나 이들 대부분은 이미 오염된 토양에 대한 정화기술로서 많은 비용이 수반되는 단점이 있다. 본 연구에서는 이들 방법과는 달리 잠재적인 토양오염지역에서 오염되기 전이나 혹은 진행 중일 때 지형학적인 특징, 지표위나 아래의 배수시스템의 재배열 및 선행계획을 통해 토양자체의 정화능력을 이용하는 새로운 정화방법을 고찰하였다. 즉, 토양자체 정화과정이 왜, 어떻게 발전되는가에 대해 단계적으로 규명하였다. 해안지역에서 오염된 바닷물의 침투와 거주지역에서 유해 라돈가스(^{222}Rn)의 조절 및 제거 등 두 가지 사례를 통해 흙의 자체정화 능력을 이용한 토양정화방법의 효율성을 평가하였다.

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