Environmental magnetic studies of roadside pollution: Identification of spatial distributions of vehicle-derived material at Mt. Hakusan, Japan.

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Environmental magnetic techniques have been shown to be useful for investigating roadside pollution. Previous studies have reported a positive correlation between: a) magnetic susceptibility and heavy metal concentration; and, b) the distance from a road and magnetic susceptibility. However, few systematic magnetic investigations on the spatial distributions of such roadside pollution have been reported in Japan. This deficiency is due to: a) lots of volcanos that supply great amount of magnetically-enhanced fly ashes; and, b) the dense population that cause huge amounts of magnetic noise. The environmental magnetic studies are reported for the Mt. Hakusan National Park in Ishikawa and Gifu prefectures. The Mt. Hakusan is an active volcano and its most recent eruption occurred in 1659. In-field as well as in-laboratory magnetic susceptibility of top soils along the Hakusan Shirakawa-go White Road show that the higher magnetic susceptibility is observed on soils collected near the road. In addition, there is a positive correlation between mass susceptibility and heavy metal contents. Based on rock magnetic measurements, the major magnetic mineral in top soils is pseudosingle- to multi-domain magnetite. The Day plot and crossover plot analyses indicate additional inputs of multi-domain magnetite to the top soils near the roadside. Furthermore, the rock magnetic and geochemical analyses of Japanese cedar tree barks show a positive correlation between saturation isothermal remanent magnetization intensity and Zn concentration and estimate the spatial distribution of single-domain magnetite derived from passing vehicles. The results show that detailed environmental magnetic analyses of top soils and tree barks are effective methods to monitor spatial distribution of pollution associated with vehicle traffic even in an active volcanic region.

Keywords: Environmental magnetism, Roadside soil and tree bark contamination, Active volcano, Japan

Distribution of radioactive Cs in Iitate soil, Fukushima: Multivariate analysis and numerical modeling approaches

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The transport of radioactive Cs in soil has been extensively studied. Many complex numerical models have been introduced to elucidate the migration mechanism of Cs in soil. The models usually required a lot of parameters which are not always available or hard to get, thus their applicability is still limited especially in a large field due to lack of input data. Moreover, the uncertainties and heterogeneity of soil physical and chemical properties may cause the simulation and prediction to be less accurate. We hypothesized that all parameters theoretically associated with the transport of Cs in soil were not always important for the prediction. Depending on specific field conditions, the prediction could be done solely based on fewer important parameters yet getting adequate prediction accuracy. This study aimed to elucidate the distribution and migration of Cs in surface soil, and to support future development of mechanism model for effectively predicting Cs transport in Iitate soil. Cs concentrations in top 30-cm surface soil were monitored in 2013-2015 at 12 plots in an abandoned forest located 40 kilometers northwest of the Fukushima Daiichi NPP. We used multivariate statistical analysis techniques to classify and compare the differences in distribution of Cs under field conditions. The analysis characterized the distribution states and pointed out the most important parameters that possibly influenced the migration of Cs in Iitate soil. A mechanism model was developed based on the physical and chemical processes associated with the above important parameters to simulate and predict Cs transport in surface soil. The results indicated soil organic carbon was highly associated with the distribution of Cs in soil. Soil erosion, and soil deposition tent to be the most important processes affect the transport of Cs in surface soil, while litter layers significantly affected the downward migration of Cs in soil profile.

Keywords: radioactive cesium modeling, multivariate analysis, Fukushima

How important is soil aggregation in regulating the activity of enzymes involved in the depolymerization of soil organic nitrogen?

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The process of nitrogen (N) mineralization in soils is regulated by extracellular N-acquiring enzymes (e.g. protease and chitinase) as N- containing organic polymers such as protein and chitin need to be depolymerized into monomers prior to microbial uptake and intracellular metabolism. In addition, this depolymerization could be regulated by the presence of soil aggregates which can protect soil organic N from enzymatic attack. However, the direct impact of soil aggregation on modulating the activity of enzymes involved in N mineralization has not been fully elucidated. Thus we tested the following hypotheses: (1) soil de-aggregation would promote N mineralization due to increased availability of organic N, and (2) there would be a stronger correlation between the mineralization rate and potential enzyme activities in de-aggregated soils than aggregated ones. In the present study two different soils from grassland (GL) and arable land (AL) respectively were air-dried and sieved for isolation of three fractions (4.75-2mm, 2-0.25mm and 0.25-0.063mm) of soil aggregates. For aggregate soil samples, three fractions were mixed based on the following proportion: 24g of 4.75-2 mm, 24g of 2-0.25 mm and 6g of 0.25-0.063 mm fraction. Corresponding de-aggregated soil samples were prepared by physical disruption with a pestle and mortar. To quantify N mineralization rate, anaerobic incubations of the soils at 26 were conducted for 10 days. Using the soils harvested from the aggregated and de-aggregated samples, potential protease and chitinase activities were determined using colorimetric assays.
The first hypothesis was supported for both land uses as N mineralization rates were significantly higher in de-aggregated soils than in aggregated ones ($P < 0.05$). The second hypothesis was supported in the case of the GL soil: significant correlations ($P < 0.05$; $r > 0.89$) between N mineralization rate and protease and chitinase activities were detected in de-aggregated soil whereas correlations for aggregated soils were weaker and not significant ($P > 0.05$; $r > 0.7$). For AL soils, only chitinase activity was reliably above the limit of detection of the assay. There were no significant correlations between the chitinase activity and N mineralization rate for both treatments, however, there was a positive correlation ($r > 0.7$) for de-aggregated soils.
The stronger correlations for the GL de-aggregated soil indicated that soil proteases and chitinases had access to, and depolymerized, organic polymer N which was physically protected before de-aggregation. We concluded that the difference between two land uses could be attributed to tillage effects on the relative location of extracellular enzymes and their substrates.

Keywords: Soil aggregate, Extracellular enzyme, Nitrogen minralization, Depolymerization

Quantifying soil ice content with a heat pulse probe for an entire range of temperature during soil freezing and thawing

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Soil freezing and thawing is important for winter hydrology. Despite its importance, measuring in-situ soil ice content θ_I has been difficult. Volumetric heat capacity measurement with a heat pulse probe (HPP) has been used to quantify θ_I (hereafter, VHC method). The VHC method determines θ_I only when soil temperature is below -5°C. In this study, we propose a new method to determine θ_I from HPP by considering sensible heat balance in soils (hereafter, SHB method). We tested both VHC and SHB methods for θ_I determination.

A HPP measures soil temperature T, volumetric heat capacity C, and thermal conductivity λ. For the VHC method, only C is used to determine θ_I. For the SHB method, a HPP is inserted into soil such that each needle is located at a different depth. When the heat balance of a thin soil layer which has boundaries at the middle of each HPP needle is considered, there is conductive heat flux at the first boundary H_1, conductive heat flux at the second boundary H_2, change in sensible heat storage ΔS, and latent heat flux L, *i.e.*, H_1-H_2-ΔS=L. H_1, H_2 and ΔS can be estimated from HPP measurements and equations, thus, L can be calculated. When T is < 0°C, L is associated with soil freezing and thawing. Thus, change in θ_I can be determined by dividing L by latent heat for water freezing L_f. θ_I can be determined by integrating $\Delta\theta_I$ with respect to time once T drops below 0 °C.

Soil was packed into 0.3 m long PVC columns with 0.28 m^3 m^{-3} water content. A HPP was inserted through the column wall. Additional columns were prepared for destructive sampling to determine total soil water content after soil freezing. Upper boundary temperature was initially 5°C, and then it was decreased to -15°C gradually within 24 hours. After 6 days, the temperature was increased to 5°C within 24 hours. The temperature for the lower boundary was maintained at 5°C. Transient θ_I was estimated with VHC and SHB methods.

θ_I determined by sampling was around 0.20 m^3 m^{-3}. θ_I estimated with the VHC method was close to 0.20 m^3 m^3 when T was < -5 °C. The SHB method could additionally estimate transient θ_I when T was between 0 and -5 °C but failed at T < -5°C. Thus, we measured θ_I for a whole T range by using the SHB method with T between 0 and -5°C and using the VHC method with T < -5°C.

A combination of SHB and VHC methods allowed determination of transient θ_I for the entire range of temperature during freezing. Accordingly, a HPP can be a useful sensor for monitoring θ_I under freezing and thawing conditions.

Intra-Wellbore Head Loss with both *Kinematic and Friction*

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Riverbank filtration or withdrawal of groundwater from the bank of a river is commonly practiced in many countries for obtaining sustainable and good quality of water. Groundwater flow to a well installed at the bank of a river is closely related to the aquifer-steam interactions. Up to present, most studies associated with riverbank filtration are concentrated on the vertical wells that may produce a large drawdown cone near the well. In recent decades, horizontal wells have become an interest of research among hydrogeologists, environmental scientists and engineers, due to many technical advantages over the vertical wells for thin aquifers, such as the decreasing operational cost and many technical advantages over the vertical wells. However, many previous studies on the flow into horizontal wells were based on the uniform flux boundary condition (UFBC) when treating horizontal wells, which could not reflect the physical processes of flow inside the well accurately. In this study, we developed solutions of transient flow into the horizontal well in an anisotropic confined aquifer between two streams for three types of boundary conditions of treating the horizontal well, including UFBC, uniform head boundary condition (UHBC), and mixed-type boundary condition (MTBC). The MTBC model considered both kinematic and friction effects inside the horizontal well, in which the kinematic effect referred to the accelerational and fluid inflow effects. The solution of UFBC was analytically derived by superimposing the point sink/source solutions along the axis of the horizontal well with a uniform strength. The solutions of UHBC and MTBC were obtained by coupling the analytical and numerical methods. Based on this study, one can draw the following conclusions: (1) At the early stage, well specific inflow (WSI) increases with the distance along the wellbore for the MTBC model, and follows a cubic polynomial function. (2) When the point of intake is at the well heel, the values of specific capacity (SC) follow the orders of UFBC, UHBC and MTBC from high to low. (3) Comparing the solution of UFBC, UHBC, $MTBC_{Friction}$ and MTBC, one could find that the difference between them is obvious, and the dimensionless drawdown of UFBC and UHBC solution are independent to the flow rate. However, the difference of the dimensionless drawdown between $MTBC_{Friction}$ and MTBC increases with the greater flow rate. The new solution can be used not only to interpret the aquifer test data, but also to provide reference solutions to check the accuracy of numerical simulators.

Keywords: Accelerational effect, Mixed-type boundary condition, Specific capacity

One dimensional solute transport in low permeability homogeneous and saturated soil columns

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Solute transport in low-permeability media such as clay has not been studied carefully up to present, and we are often unclear what is the proper governing law for describing the transport process in such media? In this study, we composed and analyzed the breakthrough curve (BTC) data and the development of leaching in one-dimensional solute transport experiments in low-permeability homogeneous and saturated media, to identify the parameters controlling transport. Sodium chloride (NaCl) was chosen to be the tracer. A number of tracer tests were conducted to inspect the solute transport under the conditions of having the same column diameter but with different column lengths, or having the same column length but with different column diameters. Tracer tests with non-smooth inner walls of the soil columns were also conducted. The modeling approaches considered were the Continuous Time Random Walk (CTRW), Two-Region Model (TRM), Classical Convection-Dispersion Equation (CDE) and Fractional Advection-Dispersion Equation (FADE). Both the breakthrough process and the leaching process were analyzed and the results indicated that the breakthrough process was Fickian, whereas the leaching process was non-Fickian. Higher values of coefficient of determination (R^2) and lower values of root mean square error (RMSE) were observed with respect to the fits of CTRW, CDE, TRM and FADE. However CDE and TRM failed to characterize the transport behavior in leaching. The CTRW and FADE models were better in capturing the full evaluation of tracer-breakthrough curve and late-time tailing in leaching.

Keywords: Solute transport, Low permeability media, Breakthrough curve

Computation of seepage-induced erosion of soils by solving the Darcy-Brinkman equations

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The numerical analysis of the soil erosion induced by seepage flows is presented. To the end, the following three aspects need to be computed: Water flow fields, onset and speed of erosion and boundary tracking between the soil and the water phases. The author employ the Darcy-Brinkman equations in order to compute the water flow fields around the soils, which easily enable the simultaneous analysis of the seepage flows in the porous media and the water flows in the fluid domain. The onset and the speed of the seepage-induced erosion is predicted by an empirical formula from the flow velocity and the pressure gradient of the seepage water. The boundary tracking scheme based on the phase-field equation is applied for tracking the soil boundary changing with the erosion. The numerical results have revealed that the combination of the above three aspects achieves the stable computation of the seepage erosion.

Keywords: Internal erosion, Numerical analysis

Pollution on the grounds broken by open-cast mining and of their rational ways of re-vegetation inside Mongolia.

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Abstract-Open-cast mining of deposits brings the greatest damage to an environment. Under current legislation, all opened cast mining should be voluntarily corrected. Extraction of minerals - process of extraction of mineral raw material of bowels. Such resources of Mongolia are gold, silver, copper, uranium, and coal. Extraction of these minerals can affect an environment very strongly. Waste which very often contains heavy metals and chemicals, can seriously pollute soil and superficial waters. The people living near to places of extraction of minerals, depend on access to pure fresh water. Outflow of toxic substances adversely influence with support of existence and a biodiversity. The majority of technologies of extraction of minerals demand enormous quantity of water. For a branch of valuable metals, pure coal or minerals from sand or rock, it leads to downturn in the level of waters, complicating access to water sources without the corresponding equipment. By development of deposits of uranium ore people can receive a harmful doze of irradiation at extraction, transportation, use, and accommodation of waste.

Keywords: mining;dust;pollution;coal;waste;

DIFFUSION OF VARIOUS ION SPECIES THROUGH GEOSYNTHETIC CLAY LINER UNDER ELEVATED TEMPERATURES

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Geosynthetic clay liners (GCLs) are used as a major component of landfill bottom liner in most of the modern engineered landfills. Their performance as a hydraulic barrier to landfill leachate is well known due to their very low hydraulic conductivity. However, when hydraulic conductivity is too low, the main transport mechanism through the liner is diffusive transport of solute or leachate. The diffusion properties of liner material are expected to be highly dependent on the nature of chemicals present in landfill leachate as well as landfill temperature. Recent studies have shown that temperature inside the landfill increases near the base liner due to weight of overlying waste and chemical processes involved in its biodegradation. Therefore it is necessary to investigate the performance of GCL against diffusion migration under high temperature conditions using different chemical species.

In this study solute diffusion tests were performed on bentonite component of a commercially available typical GCL Bentofix®. This GCL employs Na-bentonite which is mainly responsible for its hydraulic performance. The tests were performed on pre-hydrated samples of bentonite to avoid its further swelling during the test. Salt solutions of four major exchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) each at a concentration of 0.01M were used as source solutions. Deionized water was used as receptor solution. The tests were carried out at two different temperatures 20 ^oC and 40 ^oC under atmospheric pressure.

The results showed that concentration of anion (Cl^-) in the source solution decreased with the passage of time and equal amount of concentration increased in the receptor solution for all the four types of solutions. However, the cations showed a different behavior depending on the nature of each cation. The concentration of Na^+ in the source solution did not decrease significantly with time which was possibly due to presence of abundant Na^+ cations at the exchange sites of the bentonite sample. These exchanged cations resisted further diffusion of Na^+ cations from the source solution. However, an increase in Na^+ cation was observed in the receptor solution with the passage of time which is mainly due to diffusion process occurring between the sample and the receptor solution. Contrarily, the concentration of cation in source solution decreased with time for all other cation solutions. The increase in concentration of these cations in the receptor solution was found negligible. A further examination of the samples taken from receptor solution showed that a significant amount of Na^+ diffused from the bentonite sample to balance the net negative charge in the sink compartment arising due to diffusion of anions. The results were interpreted as the possible cation exchange process occurring in the bentonite sample due to high affinity of K^+, Ca^{2+} and Mg^{2+}.

Temperature was found to have significant effect on solute diffusion coefficient for all the given ion species. The diffusion coefficient was found to increase significantly with increase in temperature. Further investigations are being carried out to study the effect of a further increase in temperature on diffusion coefficient of GCL.

Keywords: Diffusion, Contaminant transport, Elevated Temperature, GCL, Leachate

Mass transport in fault zones: transition from nonlocal to normal transport

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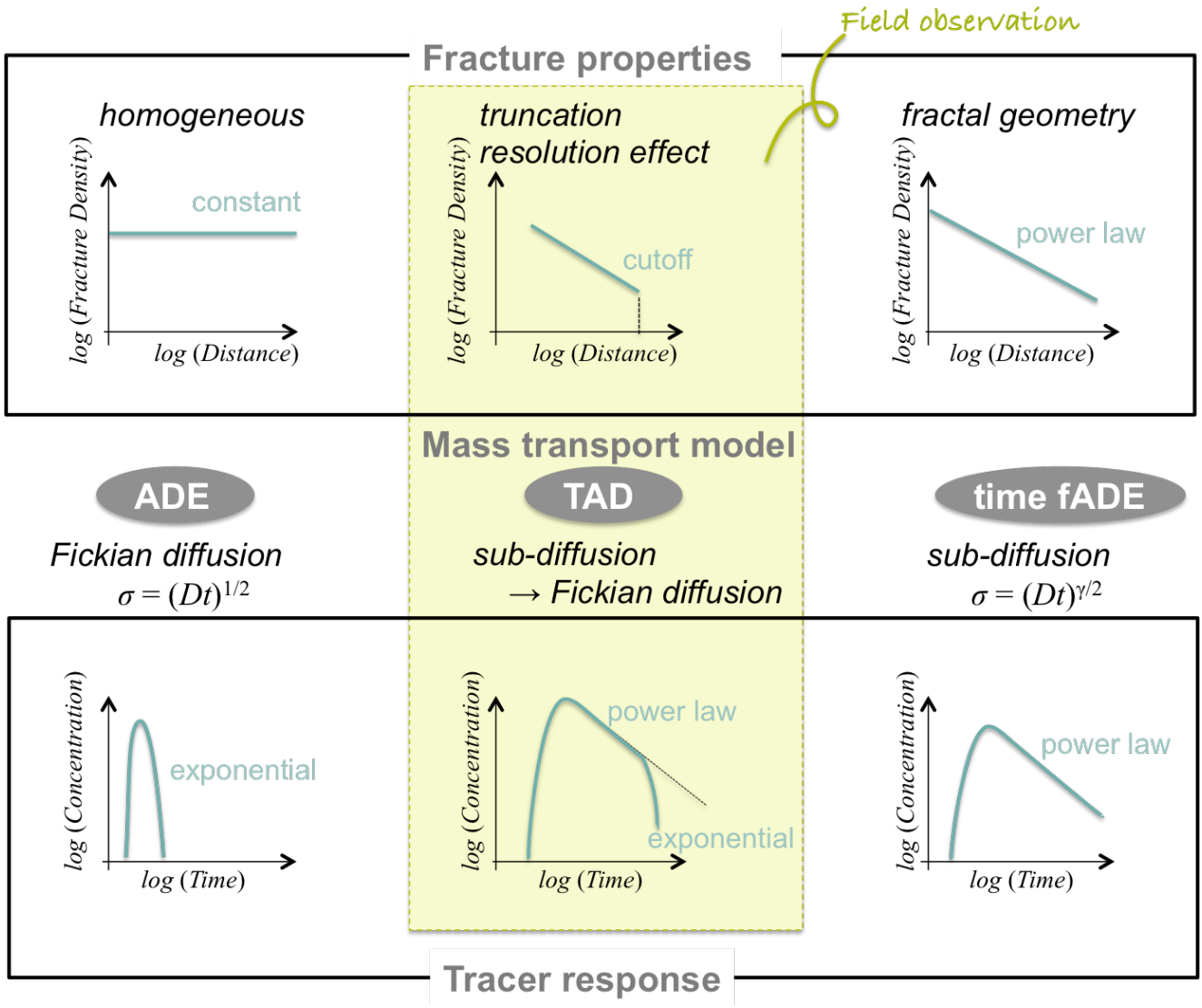
Fault zones clearly affect the flow paths of fluids at the scale of geothermal reservoirs. Fault-related fracture damage decreases to background levels with increasing distance from the fault core according to a power law. This study investigates mass transport in such a fault-related structure using nonlocal models. A column flow experiment has been conducted to create a permeability distribution that varies with distance from a main conduit. The tracer response curve describes a preasymptotic curve implying subdiffusive transport, which is slower than the normal Fickian diffusion. As long as permeability of the surrounding layers varies with distance from a main conduit, the tracer response can be modeled by the time fractional advection dispersion equation (time fADE). In contrast, if the surrounding area is a finite domain, an upper truncated behavior in tracer response (i.e., exponential decline at late time) is observed. The tempered anomalous diffusion (TAD) model captures the transition from sub-diffusive to Fickian transport, which is characterized by a smooth transition from power-law to an exponential decline in the late-time breakthrough curves.

Keywords: time fractional derivative, fractured reservoir, flow experiment, fractal scaling, truncated power-law distribution



Effects of pH on Arsenic Removal Using Magnesium-Based Adsorbents

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In some areas of developing countries, health damage caused by arsenic contained in groundwater used as drinking water has been a serious problem. In order to utilize the ground water as safe drinking water without health risk, it is necessary to remove arsenic. In our previous studies, the arsenic removal tests using several kinds of magnesium compounds (chloride, sulfide, oxide, hydroxide, and carbonate) were carried out and the results clarified that both the oxide and the hydroxide have particularly high arsenic removal performance among the magnesium compounds. However, the effects of pH on the arsenic removal performance of the magnesium compounds have not been sufficiently examined. Therefore, in this study, the arsenic removal behaviors of both magnesium oxide and hydroxide were estimated using the arsenic contaminated water with various pH (pH3 to 12).

Keywords: Arsenic Removal, Adsorbent, Magnesium Oxide, Magnesium Hydroxide, pH

Installing Artificial Macropore in Blueberry Pot to Enhance Vertical Infiltration and Fix of Radioactive Cesium.

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Fukushima nuclear power plant damaged by the East Japan Great Earthquake caused radioactive fallout around the Tohoku region. Because radioactive Cesium was positively charged, it was reported to being adsorbed to soil surface within 5cm deep. However, organic soil with less clay mineral would bind the radioactive Cesium weakly. Therefore radioactive Cesium would be transported to rhizosphere zone, which results in absorption by plants or crops.
Artificial macropores were installed to effectively transport radioactive fallout from the surface to deeper profile, by bypassing the root zone. Radioactive Cesium was expected to be adsorbed by clay minerals at the deeper profile. We carried out pot experiments for blueberries with peat moss. Artificial macropore filled with bamboo fiber (d=1cm, length=20cm) was installed in experimental pot. In this experiment, macropores were covered by plastic tubes so that solutes were effectively conducted to deeper profile without any distribution during transporting process. Six treatments were prepared such as macropore, macropore with ammonium sulfate, macropore with potassium, no macropore and no macropore with ammonium sulfate, no macropore with potassium. After one year, peat moss pots were cut into layers to determine radioactive Cesium concentration.
Results showed that, without macropore, radioactive Cesium did not move to deeper profile. When ammonium sulfate was applied without macropore, Cesium would be released from soil then it would be absorbed by blueberry. Macropore with ammonium sulfate effectively conducted Cesium to deeper profile but blueberry also absorbed it. Macropore with Potassium conducted Cesium to deeper profile to some extent and moreover, blueberries did not absorbed Cesium, probably because Cesium is a congener of Potassium.

Keywords: radioactive cesium, solute transportation, macropore

Methane transport in landfill final cover soils during precipitation

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It has been reported that landfill sites are significant sources of atmospheric methane, which is known as one of the greenhouse gases. A part of methane produced in the landfill waste layer is emitted to the atmosphere through the landfill final cover soils. Therefore, it is important to understand how methane moves through the final cover soils in order to accurately estimate the methane emission from the landfill sites. High intensity precipitation events likely induce methane eruption due to a soil-gas compression following water infiltration. However, the effects of precipitation on the methane transport in the final cover soils are not fully understood.
In this study, one-dimensional column transport experiments were conducted to examine the effects of intensity of precipitation, different dry bulk density of the cover soils, and methane production rate on the methane eruption. The disturbed soil sample (sandy loam) used as landfill final cover soils was collected. A 5% of methane was injected with different gas fluxes to the soil column (dia. 10 cm, height 30.5 cm) packed with different dry bulk densities (1.4, 1.5, 1.6 g / cm^3) from the bottom. The precipitation with different intensities was applied from the top of the column. Gas concentrations inside the column and outlet chamber placed at the top of the column were measured. Soil gas pressure, water content, and temperature inside the column were also monitored during the experiments. It is noted that batch experiments performed for the same soil sample showed methane oxidation has a little effect on eruption of methane in this study.
Main results are: (1) under higher intensity of precipitation, increase and decrease in soil-gas pressure repeated intermittently, showing the occurrences of soil-gas compression and methane eruption. (2) Higher pressure was required for the eruption events at the soil repacked with higher bulk density. (3) When the applied methane gas flux was higher, which denoted much production of methane in the waste material layer, fluctuation in the soil-gas pressure was small and occurred frequently, suggesting that eruption occurred continuously at short intervals.

Keywords: landfill final cover soils, methane gas, eruption

Evaluation of Groundwater Recharge in a Sand Dune for the Arid Land Irrigation Agriculture.

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Dryland agricultural areas are blessed with sunshine but have low precipitation. Hetao irrigation of Inner Mongolia in China (1.19 M ha with irrigated land 0.57 M ha) is located in the middle basin of the Yellow river. There is little rain, thus they take irrigation water (about 5Gt/year) from Yellow river. In recent years, water uses other than agriculture, such as industrial and domestic, are increasing year by year. Thus water distribution is another issue for water use.
We focused on sand dune as another water resource. Because particles are sandy and show uniform distribution, infiltration would be easy and evaporation would be suppressed by sandy mulch. Moreover, we observed many sand dunes are close to lakes. Therefore, we estimated sand dunes would work as water recharge area. The objectives of this study were to evaluate infiltration and evaporation control by sand dune, and to estimate the amount of groundwater recharge by sand dune. We selected a research area in which sand dune, lake and saline land are closely located. Groundwater level sensors were placed at the middle and bottom of the sand dune, and also at the saline land. Volumetric water contents and meteorological data were measured. First, column experiments were performed to evaluate the infiltration and evaporation control by sand dune (A) and saline land (B). The results showed the sand showed high infiltration ability and evaporation were suppressed after capillary water was cut. Specific yield was calculated as 0.038 using water retention curve. Then, water storage capacities were estimated as 355 mm in sand dune and 488mm in saline land, respectively. We have not included evapo-transpiraiton yet in this study, however, the groundwater recharge would also be estimated from the water storage capacities.

Keywords: Groundwater, Water resources management, Sand dune

Cs transfer to rice plants from soil after continuous application of organic materials at Iitate Village

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Iitate Village is located at about 40 km northwest from the Fukushima Daiichi Nuclear Power Plant. An agricultural fertile layer in agricultural fields was contaminated by radiocesium (134-Cs and 137-Cs) due to the accident of the Fukushima Daiichi Nuclear Power Plant in 2011. All the villagers in Iitate Village have been forced to evacuate since May 2011. The local and central governments announced that villagers who wanted to come back to the village were allowed to return home by some time in 2017 after the decontamination work. The villagers, especially farmers, returning home may face and overcome damage caused by harmful rumors or misinformation. Wiping off such damage may be very difficult so that it is necessary to continue sending correct information. We examined radiocesium transfer to rice plants from soil at paddies with continuous application of organic materials after stripping the contaminated top soil off.
We used an approximate 6x10 m paddy field at Iitate Village in Fukushima Prefecture. At first we decontaminated the field using the method of stripping 5 cm top soil off in 2013. After decontamination, we made three different treatments such as (1) mixed with rice straw harvested previous year at the same paddy, (2) only decontaminated as a control, and (3) mixed with cattle manure compost. We sampled top soils from each treatment and 134-Cs and 137-Cs concentration of the sampled soils were analyzed using a Ge semiconductor detector. The concentration of 134-Cs and 137-Cs in rice plants was also analyzed by a Ge semiconductor detector after harvest.
A transfer rate defined as total radioactive Cs concentration with 134-Cs and 137-Cs in rice plants relative to that in soil was very small in every treatment. The amount of 134-Cs was smaller than that of 137-Cs because the half-life time of 134-Cs was shorter than that of 137-Cs. The transfer rate of brown rice was lower than that of unhulled rice, meaning that rice husk contained more Cs than brown rice. Transfer rates in 2014 were lower than in 2013. It might be resulted from smaller transfer rates in 2014 because of more Cs fixed by soil and more radioactive decay having advanced.

Keywords: Cs, soil, rice, organic materials

Artificial macropore effects on carbon storage in soils

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Soil is the largest terrestrial carbon storage body, but also its carbon release caused by land management is corresponded with 20% of the fossil fuel combustion. Artificial macropore (vertical tubular hope filled with fibrous materials) has been installed to degraded soils to enhance infiltration and introduce organic carbon into deep soil layer. Results so far showed soil moisture and organic carbon were increased at the field. The technique was different from cultivation which breaks aggregate and causes soil organic matter decomposition. However, artificial macropore introduces also fresh water and fresh nutrient to the soil body, which might be potential risk for organic matter decomposition. Therefore, the objectives of this study were to conduct solute infiltration experiments with macroporous soil cell and trace the water, nutrients and organic matter content concentration during the incubation period.

Toyoura Standard soil was packed into two-dimensional cell with artificial macrpores inside. Glassfiber was used as a filling material and artificial rainfall with organic matter, nutrients were applied on soil surface. Glucose and benzoic acid were applied as organic matters. 30 C incubation was applied to glucose for three days and benzoic acid for seven days. Hele-Shaw cells were disassembled and soil samples were taken every day for Glucose experiment and two days interval for benzoic acid exmeriment.

Results showed that nutrients and organic matter were partially filtered at soil surface, but they were introduced into soil profile along with water infiltration with macropore structure. Surface organic matter was gradually decomposed but at the deeper profile it resisted decomposition. Oxygen supply was restricted at deeper profile while it was free at soil surface. Our results clearly showed that introducing organic matter along with macroporous structure had advantage over bare soil and cultivation for carbon storage at the soil body.

Keywords: carbon storage, artificial macropore, infiltration

Hydraulic analysis of two-dimensional subsurface water flow down a hillslope

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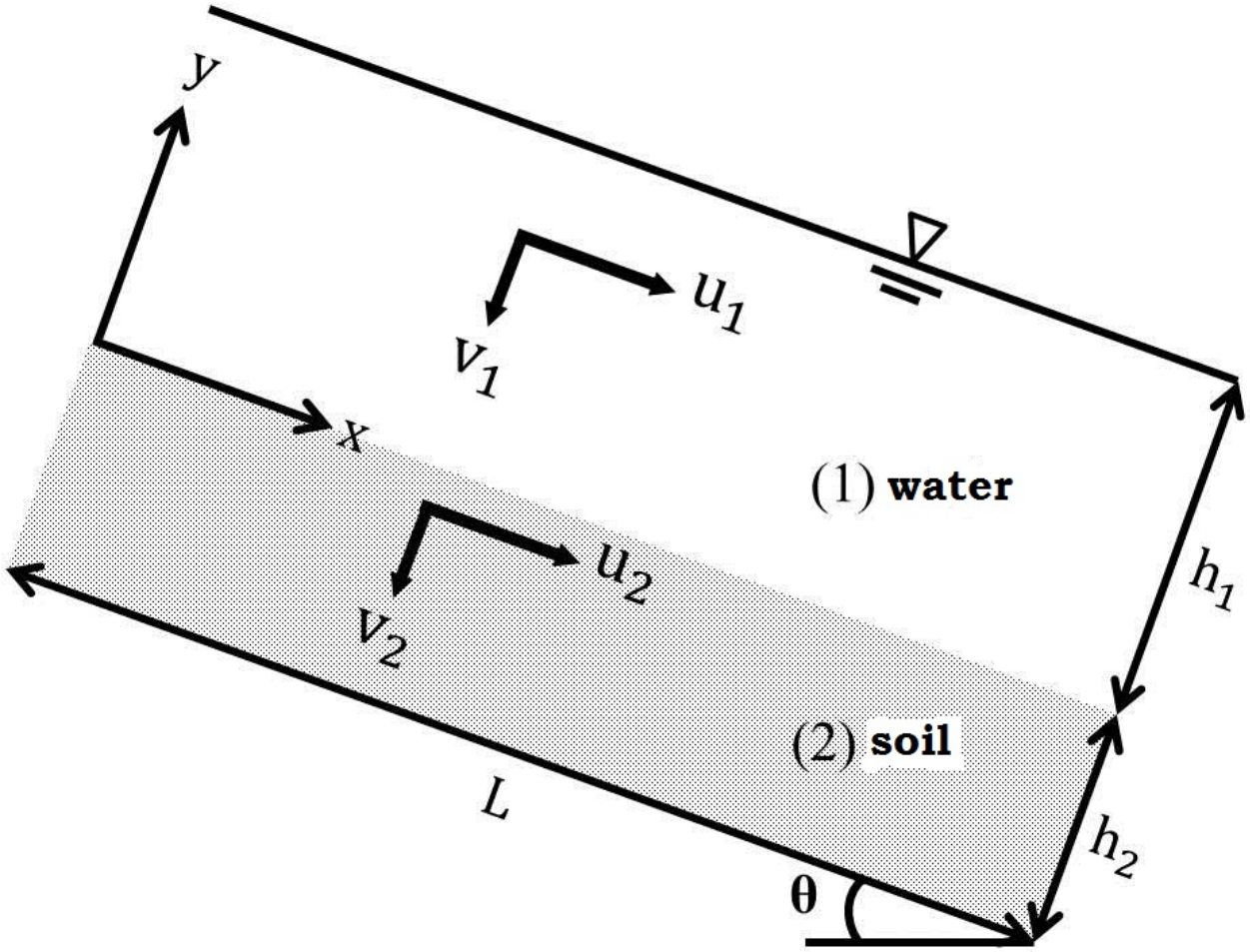
In this study, we are aimed at hydraulic analysis of a 2-D subsurface water flow down a slope. Different from the past, by additionally considering the vertical velocity and the inertia force in the momentum equation, we solve the equations in a new way. The flow field is divided into two regions (the water layer and soil layer). We derive horizontal, vertical velocity and physical quantities distribution both in the water and soil layers. In this article, the soil layer is regarded as an isotropic porous media so that the flow velocity on the ground surface is nonzero. For the momentum equations of the water and soil layer, we respectively adopt the Navier-Stokes equation and the Song's (1993) laminar model based on Biot's poroelastic theory. With the velocity type set by Desseaux (1999) and appropriate boundary conditions, we derive a couple of nonlinear ordinary differential equations which are solved by taking the Differential Transform Method (DTM) proposed by Arikoglu & Ozkol (2006). Finally, we derive the horizontal, vertical velocity and some other physical quantities distributions, and then compare the results with the relevant literature.

Keywords: porous media flow, subsurface flow, vertical velocity



Schematic diagram of the study

Analysis of soil macro pore network by Micro-focus X-ray CT system

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Soil has important role for water, gas, and heat transport. To understand mass transport properties in soil is essential for having effective remediation for contaminated soil and groundwater, and conservation of natural and agricultural lands. The mass transport properties can be controlled by soil macro pore network. In recent years, visualization technique for soil macro pore network by using a micro-focus X-ray CT system have been markedly developed and many studies using the system have already been carried out. However, previous studies have mainly focused on a sand with simple grained structure and analysis of undisturbed soil has not been conducted sufficiently. Therefore, the objectives of this study were to investigate relationship between mass transport parameters and soil macro pore network based on analysis using Micro-focus X-ray CT system. In this study, intact soil samples were taken from orchard land in New Zealand and the samples were used.
Statistical data were acquired after using Micro-focus X-ray CT system and the data were finally processed as average and standard deviation data. For example, tortuosity that is one of the important mass transport parameters in soil, was obtained from two different methods. One was calculated based on measured gas diffusivity and the other one was calculated by analysis using Micro-focus X-ray CT system. These calculated values showed almost same tortuosity. The value of mass transport parameter increased with having more complex soil macro pore network.

Keywords: Micro-focus X-ray systen, undisturbed soil, macro pore network

Effects of Water Flux and Bubble Characteristics on Nano-Bubbles Transport in Porous Media

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Potential applications of nano-bubbles (NBs) have drawn more attention, especially in environmental engineering fields such as soil/groundwater remediation. Understanding a transport mechanism of NBs in soils is essential to effectively pursue remediation techniques using NBs. In this study, one-dimensional column transport experiments using glass beads were conducted, where NBs water created by either air or oxygen were injected to the column with different water fluxes. The turbidity, pH, EC, DO, and bubble size distribution in the effluent were measured. Effects of water fluxes and bubble characteristics such as (gas species, bubble concentration, and bubble size distribution) on the NBs transport were investigated based on the column experiments. The results showed that relative turbidities (measured turbidity in the effluents / turbidity in the initial NBs water) during the NBs water injection were lower at lower water flux condition. Higher relative turbidities in the effluents were observed for O_2-NBs at the same water flux condition that those for Air-NBs, suggesting higher mobility of O_2-NBs in porous media. Column experiment with NBs with lower average bubble size and higher bubble concentration showed more gradual increase of relative turbidity in the effluents with time.

Keywords: nano-bubbles, transport, porous media

Adsorption characteristic and permeability for three mixed materials in Sri Lanka

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In developing countries including Sri Lanka, municipal solid waste is often dumped directly without incineration or any other treatments, resulting in groundwater contamination by leachate originated from the dumped waste inside. Because the leachate contains harmful chemical compounds such as heavy metals, it is important to treat the groundwater contaminated by leachate with low-cost and maintenance free systems. Permeable reactive barrier (PRB) system is suitable as in-situ remediation technique for the contaminated groundwater. In this study, adsorption (for Cd and Pb) and permeability characteristics were evaluated for locally available and low-cost materials (soil, coconuts shell biochar, and crushed brick) obtained from Sri Lanka as filling materials in the PRB system. In the experiments, the mixed materials with different ratios were used. Maximum adsorption capacity for both Cd and Pb was the highest observed in biochar 100%. For the permeability characteristics, hydraulic conductivity for the mixed materials generally increased with decreasing degree of compaction. The mixed material, soil 25% + biochar 25% + brick 50%, showed the highest hydraulic conductivity at degree of compaction with around 75%, showing more than 10^{-3} cm/s.

Keywords: Leachate, Permeable reactive barrier (PRB), Adsorption Characteristic, Hydraulic Conductivity, Degree of compaction

Effect of Artificial Macropore Installation in Subtropical Soils to Reduce Surface Flow at Sugarcane Field

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Artificial maropores were installed at subtropical red soils to reduce surface flow at sugarcane fields. The fields were suffering from heavy rain which is increasing these days because of climate change. Surface flow causes soil erosion where soil particles were directly delivered into sea with coral leaf. Soil particles would block off the sun and also nutrient rich water damage the coral leaf. Therefore, reducing surface flow with soil particles is crucial for protecting subtropical natural environment. However, conventional sugarcane employs cultivation and fresh planting every year. Agriculture soils are soft with cultivation and fresh planting needs bare soils. In that situation bare soil easily causes surface flow and soil particle loss. Non tillage or reduced tillage are strong countermeasures for those situation, however, agricultural farmers show little appreciation for non-tillage management probably because it seems like uncontrolled or abandoned.
Therefore in this research, we installed artificial macropores into the fields as an option for these situations. Artificial macropores with bamboo fibers were installed 1-m interval for conventional tillage field and non-tillage field. Soil moisture sensors were also installed at 10 and 30-cm deep soil. Rainfall was measured with tipping bucket and surface flow was measured with partial flume.
Results showed that at conventional tillage field, soil moisture sensors at 30cm showed higher water content than 10cm after heavy rain. Surface flow was reduced after macropore installation at tillage field, while non tillage field did not show the descent. These results show that installation of macropore to tillage field reduce the surface flow while enhancing vertical infiltration. However, tubular macropore installation was tedious and time consuming. Here we installed another artificial macropore, namely “linear macropore ”for which macropores were created by subsoiler and fibrous materials were filled to reinforce the structure. The first result with heavy rain showed surface flow was decreasing when compared with bare soil. Its structure was also resistible for clogging when compared with liner macropore without fillings. We are planning to observe field condition next several months to evaluate this technique.

Keywords: artificial macropore, sugarcane, surface flow

An Investigation of Remediation Reagents Injection at a Groundwater Contamination Site by Using ERT and SP Method

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The treatment of groundwater contamination is complicated and difficult, especially for extensive distribution of contaminant or non-removal source of contamination. Whether the remediation reagents can effectively transmit to the target area or not is important. In this research, we combine electrical resistivity tomography method (ERT) and self-potential tomography method (SPT) to investigate the diffusion and spatial distribution of remediation reagents at a large groundwater contamination site. We inject flowable reagents near the source of contamination, and define its preferential flow pathways and diffusion direction by ERT and cross-well ERT. On the other hand, we inject non-flowable reagents at the forefront of contamination to prevent the downstream diffusion from contaminant, and image the long-term existence of injected reagents from two-weeks monitoring of cross-well ERT, 3-D ERT, and SPT. As a result, combining cross-well ERT with monitoring wells can make the wells not only for groundwater sampling and remediation, but also for geoelectrical investigation to enhance the wells' efficiency.

Keywords: ERT, SP, Resistivity, Groundwater, Pollution, Remediation

Thermal non-equilibrium between solid and liquid phases in forced convective heat transport

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The thermal equilibrium between the solid and the liquid phases is generally assumed for numerical simulations in heat transport through soils. However, the validation of this assumption is not well examined, especially in heat transport through coarse materials that have low thermal conductivity. In this study we conducted one-dimensional heat transport experiments using different size fractions of glass beads and plastic balls to examine the validation of thermal equilibrium assumption. In the experiments, hot water (38℃) was injected to the 50-cm long column packed with glass beads or plastic balls. The temperatures of the solid and liquid phases were measured independently. The convection-dispersion equation with the assumption of the thermal equilibrium was applied to the measured thermal responses under different water fluxes. We found that thermal conductivity of the materials was not a dominant factor that affects thermal equilibrium between solid and fluid phases. In addition, the thermal dispersion coefficient obtained by applying the convection-dispersion equation to the thermal responses in the solid phase and fluid phase were similar.

Keywords: Thermal equilibrium, Thermal non-equilibrium, Thermal dispersion

Compaction and consolidation characteristics for representative industrial wastes in Japan

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Waste disposal sites have important role for human activity. Because, it is difficult to build new disposal sites in Japan due to the lack of land, effective use of limited space in existing waste disposal sites is essential. The control of geotechnical properties for waste materials such as compaction and consolidation are key factors for reducing disposal space.In this study, compaction and consolidation characteristics for waste materials of sludge (D < 2.0 mm), crushed concrete (2.0 mm < D < 9.5 mm), and incineration ash (D < 2.0mm) were investigated with their different mixing proportions based on mass ratio. Standard proctor compaction test was carried out according to JIS A 1210. Consolidation test was carried out by using the mixed waste samples (D < 2.0 mm) based on JIS A 1217.
For the compaction characteristics of two mixed and three mixed samples, relationship between maximum dry density and mixing proportion of crushed concrete and/or incineration ash showed strong positive linear relation. Crushed concrete and incineration ash have completely different particle size distribution, however, the mixed samples of sludge and crushed concrete and/or incineration ash showed almost same compaction characteristics. Coefficient of compression for the mixed sample of sludge and incineration ash gradually decreased with increasing the mixing proportion of incineration ash, while for the mixed sample of sludge and crushed concrete, they drastically decreased with increasing the mixing proportion of crushed concrete. For the three mixed samples, they drastically decreased with increasing the mixing proportion of crushed concrete and/or incineration ash. Also, coefficient of volume compressibility and coefficient of consolidation for the samples containing crushed concrete clearly decreased and increased, respectively, as compared to the sludge. Therefore, the mixed sampled containing crushed concrete showed different consolidation characteristics.

Keywords: Compaction, Consolidation, Sludge, Crushed concrete, Incineration ash, Mixed waste materials

Effects of air entrapment in a soil pipe on initiation of soil pipe flow

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Introduction

Soil pipes, continuous macropores parallel to the slope, are often observed at hillslope. Recent intensive field studies showed that soil pipes had an important role in hillslope hydrological processes as well as slope stability. Laboratory experiments using artificial soil pipes have investigated the effects of soil pipe properties on groundwater table under steady state water flow, slope stability and erodibility of the pipe wall. However, most laboratory studies as well as field researches rarely examined the state of water flow in the soil pipe directly, especially in the closed soil pipes. It is because that it is difficult to observe inside of natural soil pipes without destruction of the slope. Even at laboratory, soil water pressure around the soil pipe indirectly estimated occurrence of soil pipe flow. The objective of this study is to clarify water flow dynamics in the closed soil pipe directly by the laboratory experiment using soil box with an artificial soil pipe.

Materials and Methods

An acrylic plastic pipe, 7 mm inner diameter, 10 mm outer diameter, and 50 cm long, was used as an artificial soil pipe. Drain holes with 3 mm diameter were evenly opened on the pipe wall. Soil pipe was covered by nylon mesh to prevent sediment inflow. Soil pipe was connected to pressure transducer measure air pressure in the soil pipe. Two-needle electrodes were set inside the soil pipe to detect water flow in the soil pipe.

Acrylic plastic rectangular box, 100 cm long, 5 cm wide and 22 cm high, was used. This box was divided into 90 cm long soil section and 10 cm long reservoir section by stainless steel mesh. At the downward outlet, three drain holes were opened at 3 cm high and covered nylon mesh. Toyoura sand was packed to the soil section with a dry bulk density of 1.43 g cm^{-3} to a thickness of 18 cm. Artificial soil pipe was buried at center of soil section and 1.5 cm high from the base of the soil box. Water was supplied to the reservoir at constant inflow rate until steady state water flow was achieved. During experiments, outflow rate, soil water pressure and water level in the reservoir were measured. Four experimental conditions changing occurrence of soil pipe (NoPipe or ClosePipe), air continuity between inside of soil pipe and atmosphere (AirPipe), and inflow rate (3.6 or 0.9 L h^{-1}) were examined.

Results and Discussion

Groundwater table In ClosePipe, only under high inflow rate (3.6 L h-^{1}), soil pipe flow occurred then groundwater level decreased compared to that without soil pipe. Initiation of soil pipe flow depended on inflow rate. Once soil pipe flow occurred, soil pipe flow did not cease after inflow rate decreased. In AirPipe, soil pipe flow started even under low inflow rate.

Water and air pressure and electrode response In ClosePipe under high inflow rate condition, water saturation at the upper end of the soil pipe firstly occurred, while air pressure in the soil pipe still equaled to barometric pressure. Soon after that electrode in the soil pipe responded, showing initiation of soil pipe flow. The timing of electrode response corresponded to that of water saturation at same position estimated by temporal variation of water pressure in soil matrix. On the other hand, under low inflow rate, air pressure in the soil pipe firstly rose, which means air in the soil pipe had been isolated from atmosphere. Entrapped air hardly escape to atmosphere, then prevented invasion of water into the soil pipe. No electrode response under this condition supported no water flow in the soil pipe.

Water flow in closed soil pipes starts only when water saturation at a part of soil around soil pipe occur before whole soil around soil pipe reaches enough water content for air entrapment. Otherwise, soil pipe with air pathway such as vertical macropores like AirPipe experiment could initiate pipe flow.

Keywords: Soil pipes, entrapped air, laboratory experiment

The relation of Soil water repellency appearance characteristics and soil physical-chemical properties in the domestic agricultural land and New Zealand pasture land

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Soil water repellency (SWR) is the natural phenomenon which has been commonly related to organic compounds and aggregation in soils. Soil Water Repellency in the field will cause non-uninform infiltration and surface run-off, soil erosion. Especially, agricultural land under organic management may be particularly vulnerable to SWR as a result of frequent organic fertilizer applications. The objectives of this study are i) to investigate the spatial distribution of SWR at the surface, ii) to investigate the difference of SWR at the surface of a soil in the field and laboratory, and iii) to identify the relationship between the SWR and soil physical chemical parameters. Two sites were selected; greenhouse vegetable farm at Mizuho-farm, Miki-city, Hyogo prefecture in Japan and pasture land at Tihoi-farm, Waikato in New Zealand. Field measurement and soil sampling were carried out at Mizuho-farm in December 2013 and October 2014, at Tihoi-farm in February 2014 (summer) and December 2014 (spring). At the result, SOC and C/N are not related to field SWR appearance compare to field water content. And comparison of laboratory SWR and field SWR shows that higher clay content will make higher field SWR by surface roughness.

Keywords: Soil water repellency, Elemental analysis

Numerical Analysis of Fate and Transport of Pharmaceutical Residue Ketoprofen and Its Transformed Products in Paddy Soils

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Ketoprofen (KPF), one of the analgesic antipyretic drugs, has been found in treated wastewater due to incomplete removal of pharmaceutical compounds at wastewater treatment plants. Although its toxicity to the aquatic ecosystem is relatively known, that of its transformed products is relatively unknown. Recycling of treated wastewater in agriculture becomes inevitable as demand of freshwater is growing due to global population explosion. In a part of Ehime prefecture, Japan, some paddy fields have been irrigated with treated wastewater. However ecotoxicity of using treated wastewater has not been fully investigated.
In this study, the fate and transport of KPF and its transformed products in a paddy field was numerically investigated. Transport characteristics of KPF and its transformed products in saturated soil were obtained from the column experiment. Numerical simulation of fate and transport in paddy soil was conducted using HP-1 program, which is a coupled program of HYDRUS-1D and PHREEQC, so that different degradation paths can be taken into account. To mimic the surface ponding, a two layer model was constructed where the top 5-cm layer was used for surface ponding. In this layer, photolytic degradation of KPF with two different known daughter products was considered. In the lower layer, which is a 15-cm plow layer, biodegradation with two different known daughter products was considered. Photolytic degradation depends on the proportion of light intercepted by growing rice. In this study, different scenarios for light interception, from no interception to full interception, were considered. When 50 % or more light is intercepted, KPF was completely degraded by solar in surface ponding and the photodegraded products may reach at the bottom of the plow layer. The concentrations of both of transformed products were much lower than that of KPF in irrigation water. On the other hand, when light is completely intercepted, the 50 % of KPF in the soil will be degraded before reaching to the bottom of the plow layer. The concentration of biotransformed products at the bottom of the plow layer will be two or three orders of magnitude less than the input concentration of KPF. This study investigated numerically the risk of using treated wastewater for paddy. Our results indicated that, depending upon the growing period, different transformed products may be leached out from the plow layer. More ecotoxicity study may be necessary for transformed products of KPF.

Keywords: Treated Wastewater, Paddy, Ketoprofen, Transformed Products, Fate, Numerical Analysis

Effects of Dissolved Organic Matter on Transport of Cesium in weathered granite soil

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To grasp migration of radiocesium (Cs) in forest soil has been one of the subjects since the accident of Fukushima Dai-ichi nuclear power plant, Japan. There is a possibility of organic matters in forest soil to have an effect on migration of Cs. In particular, dissolved organic matters (DOM), for example humic acids (HA) and fulvic acids (FA), may affect sorption and transport of Cs in soil. In this research, we studied effect of types of DOM on Cs transport by laboratory batch and column experiments.
Soil sample was collected at an abandonment forest in Iitate, Fukushima, Japan. DOM was extracted from a litter from forest in Chichibu, Saitama. For batch experiments, we measured amounts of organic matter and Cs adsorbed to the soil. Since adsorption of Cs to soil clay cannot complete during percolation of water/solution through soils, we tried three different extent of reaction time 1, 12, 24 hours. For column experiment Cs solution or Cs-DOM mixed solutions were applied by constant ponding depth. Cs concentration in discharge from the bottom of the column was measured. After the halt of the percolation, a portion of soil was sampled at each 2cm thick layer form 0-10cm in depth, and sequential extraction of Cs was conducted.
For batch experiment, there was almost no difference between selectivity constants for Cs with reaction time for 1 to 24 hours. However, determined selectivity constants were smaller than those reported for the equilibrium constant. Amount of HA adsorption was more than other DOMs adsorption. In addition, when Cs-HA mixed solution was reacted for 24 hours, amount of Cs adsorption increased with increase in HA adsorption.
For column experiment, Cs from CsCl solution accumulated within surface 2cm thick layer, while Cs mixed with DOM solutions could move into 10cm deep soil layer. Sequential extraction suggested most of Cs at deeper layer was complexed with organic matter.

Keywords: Fukushima, Cesium, Dissolved organic matter, Humic Acid, Fulvic Acid

Characterization of Polychlorinated Biphenyls (PCBs) from Soil and Sludge

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Polychlorinated biphenyls (PCBs) are a group of manufactured organic chemicals that contain different congeners. Although production of PCBs was banned by the Stockholm Convention on Persistent Organic Pollutants in 2001 due to their environmental toxicity, PCBs were widely used as coolants and lubricants in transformers, capacitors, and other electrical equipment worldwide especially in developed countries. Environmental contamination by PCBs remains one of big issues today because they are chemically stable and resistant to degradation in the natural environment. Characterization of PCBs from soil and sludge is typically difficult because of varieties of congeners together with strong adsorption of PCBs to soil organic matter. Referring to EN 16167: 2012, and using the samples provided by Federal Institute for Materials Research and Testing, BAM, this study examined the applicability of gas chromatography with electron-capture detection (GC-ECD) and gas chromatography with mass selective detection (GC-MS) for characterizing PCBs. In addition, a comparison between the results obtained by using different columns, specifically, DB-5MS and HT8-PCB was made to investigate potential effects from the column being used.
The results demonstrated that both GC-ECD and GC-MS can be used to analyze PCBs with an acceptable accuracy. Analytical values of concentrations of different congeners, specifically, TrCB#28, TeCB#52, PeCB#101, PeCB#118, HxCB#138, HxCB#153, HpCB#180, are dependent on analytical approach due to the differences in standard materials being used and potential interference between different congeners. Compared with the analytical approach, the effects of column are negligible. Test results were certified by BAM and, therefore, the procedures and approaches used in this study may provide a standard reference for characterizing PCBs in both soil and sludge.

Keywords: Soil Contamination, Polychlorinated Biphenyls, Analysis Accuracy, Soil, Sludge

Change in groundwater quality during the long term thermal loading and cooling

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Recently, the subsurface temperature increase due to global warming, heat island phenomenon, the waste heat from the underground structures and some other causes has been observed worldwide. Increase in subsurface temperature might affect groundwater quality (e.g., dissolution of toxic substances such as heavy metals in the soil, generation of metabolic substances by the change of microbial activity). But its effects are not well understood. Therefore, the purpose of this study is to investigate the effects of subsurface temperature increase on groundwater quality. In this study, the subsurface heat exchanger installed in the experimental site at Saitama University campus and water of 40 ℃ and 60 ℃ was circulated in the heat exchanger for the thermal loading test. The groundwater quality was measured at four monitoring wells with two aquifers. As a result of thermal loading, the concentration of several components (K, Na, NH_3, B, Li, Si, As) increased with subsurface temperature increase, while the concentration of a few components (Mg, Ca) decreased. These results show that the subsurface temperature increase affects groundwater quality.

Keywords: groundwater quality, subsurface temperature, thermal loading

A Case Study of Combining Geophysical Prospecting Techniques at a Dump slag Contaminated Site

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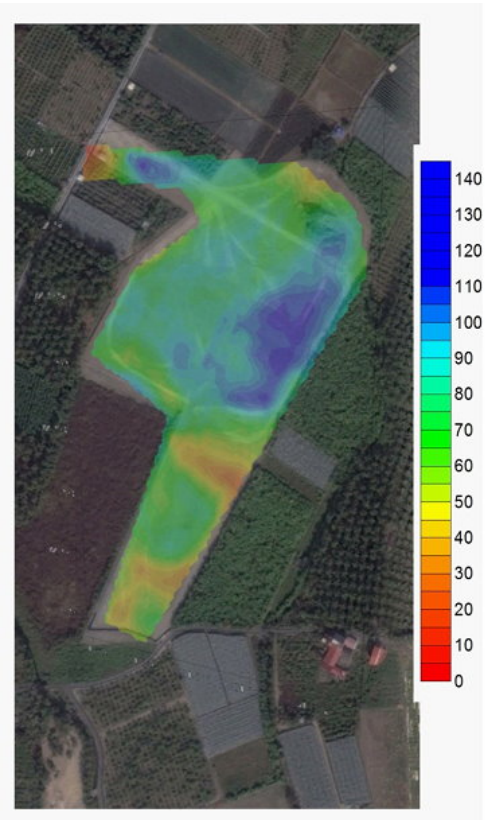
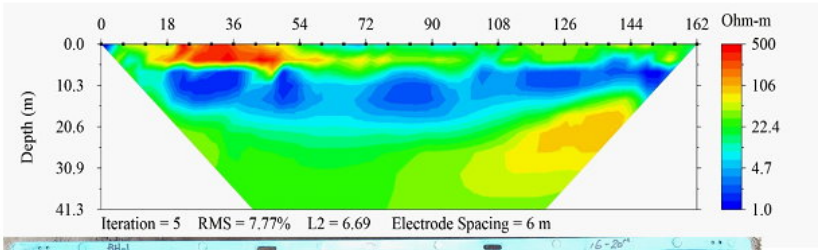
In pace with a growing focus on environmental protection, geophysical techniques to characterize abandoned hazardous sites contribute necessary information for remediation. Study of physical property distribution in the subsurface allows insight relevant to the successful investigation of such sites. Electrical Resistivity Image (ERI) is one of the most effective and stable geophysical techniques for contaminated land investigations where it is generally desirable to minimize ground disturbance. Unethical operators in the past dumping furnace slag, resulting in farmland water is blue. The site is located next to a low-density residential community and was previously considered unattractive. It is now being developed for domestic infrastructure and has to be cleaned. Records of dumping activities are poor. In order to estimate the budget of future remediation, ERI works were used to determine buried slag geometry such as the thickness of fill and the spread of waste carbide.
In this study, we presented the investigation outcomes of electrical resistivity tomography (ERT) and Electromagnetic (EM) at the illegal dump site. Evaluation of ERT/EM technique deployment in detecting slags buried and assessment of remediation efforts are also discussed. Results indicated zones with anomalously low resistivity to be associated with contaminated slags presence.

Keywords: Electrical Resistivity Image (ERI), Electromagnetic (EM), Slag





Tracking Wetting Front Seamlessly during Infiltration using Array Ground Penetrating Radar

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As an array ground penetrating radar (GPR) electrically switches any antenna combinations sequentially in milliseconds, both common-offset gather (COG) and multi-offset gather (MOG) data can be acquired almost seamlessly. The main objective of this study was therefore to determine if COG and MOG surveys by the array GPR which allows 110 different antenna combinations could detect a wetting front during vertical field infiltration. An infiltration experiment was conducted at an experimental field inside Tottori Sand Dune, Japan. Time-lapse radargrams of COG and MOG by the array GPR clearly show the wetting front evolution with time. Reflection signals in MOG radargrams agree well with two-way travel times predicted from dielectric constant independently observed with a soil moisture sensor. This study confirms the usefulness of the array GPR for monitoring and quantifying the infiltration process in the field.

