Transport of Pesticides and Bacteria Through Macropores Created by Plant Root Network

File Number : CRG/2023/004624

Submitted By : Dr. Saumyen Guha
[SERB Qualified Unique Identification Document: SQUID-1966-SG-7834]

Submission Date : 15-Mar-2023

PROPOSAL DETAILS

(CRG/2023/004624)

Dr. Saumyen Guha

sguha@iitk.ac.in

Professor (Civil Engineering)

Indian Institute of Technology Kanpur

Kanpur iit, po kanpur, Kanpur nagar, Uttar pradesh-208016

Technical Details :

Scheme : Core Research Grant

Research Area : Civil Engineering (Engineering Sciences)

Duration : 36 Months **Contact No :** +919935168271

Date of Birth : 01-Nov-1966

Nationality : INDIAN **Total Cost (INR) :** 59,62,320

Is PI from National Laboratory/Research Institution ? No

Project Summary :

Several studies have indicated that the presence of macropores enhance flow and transport in the subsurface. Majority of the studies in the literature have used various forms of artificially created macropores, e.g., solid tubes, boreholes filled with fibrous materials, hollow tubular structures filled with biodegradable materials, straight as well as tortuous configurations, etc. Some have characterised the network of macropores created by the roots using advanced scanning techniques such as X-ray tomography or NMR. However, some of the major scientific questions remain unanswered, such as, role of the macropores in the spatial distribution of bacteria and associated activity in the subsurface. This has implication on the fate and transport of pesticides and organic matter since the bacterial activity may be concentrated along the preferential flow paths. Accordingly, the objectives of this proposal are: (i) to experimentally characterise enhanced transport of nutrients, pesticides and bacteria through the preferential flow paths created by the roots using artificial analogue and natural root network; (ii) to formulate, calibrate and validate a model for simulation of flow and transport of nutrients, pesticides and bacteria through the root zone soil. The experiments will be conducted with, (a) artificial root network created with wires and, (b) various agricultural plants. The experiments will be performed in the controlled environment of a plant growth chamber and in the field. In the experiments, following the application and infiltration of pesticide and bacteria, transects in the root zone will be taken to collect water and soil samples along the preferential flow paths. Pesticide and it's degradation products will be extracted using the Soxhlet technique and analysed in a GCMS. The bacteria will be characterised in terms of activity and bacterial protein. Flow and transport through the soil matrix without the preferential flow network will be characterised through a set of similar experiments with no plants. This will serve as the control in the subsequent analyses of data as well as formulation of the model. A dual permeability model will be formulated to simulate the flow. The flow velocities will be used in a two-zone composite transport model to simulate preferential transport through the macropores. The dispersion in the two zones will be characterised using conservative tracer experiments. The retardation parameters will be estimated from the experimental data through reverse simulation. Observations from the set of experiments conducted in the controlled environment of plant growth chamber will be used to estimate the parameters. The experiments in the field will be used to validate the model.

Objectives :

Our goal is to characterise the preferential flow and reactive transport through the macropores created by the root network of the plants. The specific objectives are: (i) Experimental investigation to characterise the enhanced transport of nutrients, pesticides and bacteria through the preferential flow paths created by the roots using artificial analogue and natural root network vis-à-vis soil matrix without the plant root network. Investigations will be carried out in the controlled environment of a growth chamber and in natural environment. (ii) Calibrate a dual permeability flow model using the data from the experiments conducted in the controlled environment. (iii) Formulate and calibrate a composite two-zone reactive transport model for nutrients, pesticides and bacteria through the root zone soil using the data from the experiments conducted in the controlled environment. (iv) Validate the flow and transport models using the field experiments. We will conduct the experiments with two pesticides, (a) Chlorpyrifos, the most commonly used insecticide in Indian agriculture [Nayak and Solanki (2021)]; (b) Regent GR, a phenylpyrazole insecticide commonly used in the crops. For bacterial transport, we shall use Escherichia Coli, the most commonly used analogue for the microbial transport experiments and also an indicator organism for pathogens. For nutrients, we will use the commonly used fertilisers such as, Urea and DAP.

Keywords :
pesticide, bacteria, unconfined aquifer, macropore, root network, transport

Expected Output and Outcome of the proposal :

The model and the experimental results arising out of this proposal will have the following implications: (a) Improved understanding of the transport of nutrients, pesticides and bacteria in the root zone along with their interactions and dynamics. (b) The transport model can be used to optimise the use of fertilisers. (c) The transport model can also be used to simulate transport of nutrients, pesticides and bacteria through the root zone to the unconfined aquifer underneath. Thus, it will provide a tool to assess the potential for contamination of the aquifers by the nutrients, pesticides and pathogens applied on the surface, due to preferential transport through the root network.

Suitability of the proposed work in major national initiatives of the Government:

Smart Village

Collaboration Details for last 5 Years :

Planned Collaboration for the proposed work with any foreign scientist/ institution ? No

SNo.	CO-PI Details
1	 **Richa Ojha** richao@iitk.ac.in Assistant Professor(Civil Engineering) **Indian Institute of Technology Kanpur** Kanpur IIT, PO Kanpur, UTTAR PRADESH, KANPUR NAGAR D.O.B : 18 Nov, 1985

Other Technical details:

1. Origin of the Proposal:

Water along with the nutrients are prerequisite for the plant growth. Cracks on the soil surface, earthworm burrows, and natural channels due to plant roots can bypass the water flow and solute transport to subsoil layers. These pathways are collectively termed as preferential pathways (PFPs). For the past 3 decades, research have been conducted to assess the impact(s) of these PFPs on the flow and transport, both at the laboratory and *in-situ* scale. Visualizing and quantifying attributes of the PFPs have been possible due to the recent advancements such as, X-ray CT images and NMR. Out of the macropores (ϕ > 300 μm), mesopores (30 μm < ϕ < 300 μm), and micropores (ϕ < 30 μm), the macropores were the most studied category of the PFPs. At the laboratory scale, PFPs (with ϕ > 300 μm) were mostly studied by designing artificial macropores. Despite the simplicity and the ease of doing experiments with the artificial macropores, we lack knowledge on several mechanisms at the field scale. Some of these are:

i. Natural PFPs have reactive surfaces, often with active or viable cells which the materials used to create artificial macropores lack. Therefore, they cannot simulate the reactive transport.

ii. The macropores created by the roots can acquire water and absorb nutrients from the preferential flow paths along the surface but the artificial macropores created by solid material cannot.

iii. The literature till date still lacks considerable understanding about the response of macropores in water-stressed conditions. Due to climate change, prolonged droughts are the major global challenge. Such extreme drought events will increase the soil macroporosity which will further impact the hydrologic cycle. Increase in macroporosity will promote the occurrence of preferential flow paths.

Therefore, it is extremely important to understand the interplay of the preferential flow paths and associated biochemical activities for several reasons. Some of these are: (i) understanding of the transport and bioavailability of fertilisers in the root zone and their impact(s) on crop yield which will lead to optimal use of fertilisers leading to lesser nutrient load on the environment; (ii) enhanced transport of pesticides and bacteria through the PFPs to assess potential for contamination of the unconfined aquifer. This is the primary motivation for this proposal.

2. Review of status of Research and Development in the Subject

2.1. International Status:

Research so far conducted for artificial macropores can be sub-categorised in five lots (2.1.1 to 2.1.5). These are:

2.1.1. Studies involving use of rigid structures:

Xiong et al. (2022) reported the effects of macropore diameter, density, pore wall surface area, and macroporosity on the growth of maize in compacted soil. Artificial macropores were created with the help of stainless-steel needle of three diameters, 0.5, 1, and 2 mm. The X-ray CT scan images were used to analyse pore-network and interaction of roots with artificial macropores. The results concluded that the presence of macropores in the soil decreases soil penetration resistance only around the macropores. The macropores which have aperture of the same size as that of the roots (0.5 and 1 mm) promoted the ^{15}N uptake and above ground biomass. Allaire-Leung et al., (2000a, 2000b) investigated the effect of macropore continuity and tortuosity on the flow and the solute transport. They used screen with 50 holes/cm^2 having square cross section of size 0.01 $\times$ 0.01 m^2. Tortuous paths were created by joining stainless steel screens in zig-zag manner. Authors concluded that the presence of more tortuous PFPs decreases the macropore flow and has profound impact on the solute transport as well. Lamy et al. (2009) used a cylindrical stainless-steel screen with 25 holes/cm^2 to generate the macropores and used the Darcy-Buckingham model for the flow and a mobile-immobile model in conjunction with convection dispersion equation for the solute transport. The models could qualitatively describe the flow and transport in the macropores, but failed to simulate the flow and transport quantitatively. One significant difference between Allaire-Leung et al. (2000a, 2000b) and Lamy et al. (2009) is that the former observed flow in case of unsaturated conditions, whereas there was insignificant preferential flow for Lamy et al. (2009).

Gjettermann et al., (2004) and Tofteng et al., (2002) attempted to characterize the film and the pulse flow through the PFPs. Both studies have used ceramic tube with ferrous chloride coating on inner face. Tofteng et al., (2002) used sand and Gjettermann et al., (2004) used glass beads for soil column. Gjettermann et al., (2004) found that the large diameter pores show pulse flow, whereas the small diameter pores show film flow. In contrast, Tofteng et al., (2002) observed both film and pulse flow for 3 mm diameter ceramic tube, depending on the flow rate. Both the studies concluded that sorption of Phosphorus was more for film flow than that for the pulse flow.

2.1.2. Studies involving boreholes filled with fibrous material:

Effectiveness of macropores in mitigating the effects of salinity from agricultural soil was studied by (Zhang et al., 2021). For this, vertical boreholes of 16 mm diameter were made of varying lengths 5 cm, 10 cm, and 15 cm. These boreholes were then filled with fine sand material to give them the structural stability. The saturated hydraulic conductivity was enhanced by 260 % and 309 % in the presence of macropores for mild and severe salinity of soil, respectively. As far the desalinization of farmland was concerned, significant improvement (52.1 % and 176.6 %) was observed only with 10 and 15 cm macropore lengths. To visualize the impact on above ground biomass, Alfalfa was sown, whose yield was 20 % more when compared with the one without macropore.

Mori et al., (2015) studied the effect of artificial macropores in improving drainage caused by land degradation. Straight stainless-steel pipe with 6 mm diameter and 500 mm length filled with glass fiber (average size 9 micron) was used. They observed increased infiltration leading to mitigating effects on the surface runoff but only when rainfall intensity was less than 80 mm per hour.

Mori and Hirai, (2014) compared the efficacy of artificial macropores filled either with glass fiber or paper towel fiber for studying solute transport and microbial activity in the macropores with respect to macropores without the filling of any fibrous materials. They used 27 cm long and 5 mm diameter holes. It was observed that soil columns with macropores increased solute transport irrespective of whether they were filled with fibrous material or not. The empty pores increased solute transport only for short duration, after which it might have structurally collapsed or clogged. Biological activities were measured which occurs as a response of biodegradation of Organic Carbon. Microbial activities, especially nitrification, were highest for glass fiber fill followed by the paper towel fill.

2.1.3. Straight macropores made by inserting and removing metal rods into repacked soil:

Atkinson et al., (2019) investigated the macropore location by observing the elongation of wheat roots in both dense and loose soil using X-ray CT scan images. For this purpose, two genotypes of wheats were grown in topsoil (kept in upper PVC cylinder) having bulk density of 1.1 gram/cc. Macropores were made with the help of 0.8 mm diameter and 45 mm brass rods by inserting in bottom soil (kept in lower PVC cylinder). Two scenarios for bottom soils were considered, loose (bulk density of 1.2 gram/cc) and dense (bulk density of 1.6 gram/cc). For both the genotypes of the wheat, it was observed that more colonization of roots was observed for macropores in compacted soil (68 %) as compared to macropores in loose soil (12 %). This shows that roots change its direction of growth and exploit macropores to bypass the compacted soil. It was also observed that when roots colonize in the macropores, they do not leave the pores, but instead, tend to grow inside the pores. However, if the macropores are present in the loose soil, then roots cross these macropores and very small fraction (21 %) of roots changes its direction of growth. Colombi et al., (2017) reported the effects of macropores on other agricultural crops such as soyabean and maize in addition to wheat. The results showed that the diameter of the roots should be of the similar order of the aperture of pore in order for them to grow in the macropores. Similar observations were also reported by Xiong et al., (2022). Nakamoto, (1997) and Xiong et al., (2022), attributed the colonisation of the roots to the oxygen concentration gradient in the macropores.

Abu-Ashour et al., (1998) studied the movement and distribution of bacteria in repacked soil containing artificial macropores for various initial water contents and in the presence of rainfall event. They utilized 2.4 mm diameter metal rods of length 175 mm to make artificial straight macropores. NAR E-Coli was used as a biotracer in this study. The inoculum added at the top of the column was fully recovered at the bottom with the macropores, while only $1/3^{rd}$ of the input inoculum was collected at the bottom without the macropores. When the columns without the macropores were dissected, it was found that most of the bacteria and inoculum were trapped in the top few centimetres of soil.

Nakamoto, (1997) also investigated the distribution of maize roots in artificial macropores. For this, a 4 mm steel rod was inserted in the field and removed. Author observed that the number of roots in the macropores increased with the depth. They reported that the Poisson distribution can be used to predict the number of roots expected to be found at some given depth.

2.1.4. Biodegradable artificial macropores:

Buttle and Leigh, (1997) investigated the influence of macropore connectivity on the hydraulic properties of the soil. They used 2 mm diameter biodegradable foam. This foam breaks down on wetting. Two columns were made: column A with continuous 60 cm macropore, and column B with discontinuous macropore (discontinuity of 10 cm between 25 and 35 cm). They observed that both vertical and radial hydraulic gradients increased in the presence of macropores. Presence of continuous macropores increased advection and decreased dispersion.

2.1.5. Aluminium and Nylon mesh wrapped around wooden rod:

Akay and Fox, (2007) designed artificial macropores such that same soil column can be used to study the impact of various lengths of macropores. They used 2 mm aluminium mesh wrapped around wooden rod. On this aluminium mesh, a Nylon mesh of 0.1 mm was wrapped. The net diameter of the macropore was 1 cm and maximum length of the attainable macropore was 75 cm. Aluminium mesh provided the structural stability against collapse and Nylon mesh protects the macropore from clogging. Since the objective of the study was to quantify the direct drainage connectivity of open and buried macropores on subsurface drainage in terms of total flow, microbial growth was prevented in the pore space by adding Thymol in the infiltrating water. The portion of total flow diverted to the macropores increased with increase in the length of buried macropore.

2.2. National Status:

To the best of our knowledge, no such work was/in progress in India where artificial macropores were studied to quantify its attributes (water flow and solute transport).

2.3. Importance of the proposed project in the context of current status.

Review of the existing literature shows that the macropores are capable of enhanced flow and transport in the subsurface. However, majority of the literature has conducted experiments with the macropores created artificially and/or has focused on growth of the roots in the macropores. No literature reported transport and microbial activity in the macropores vis-à-vis soil matrix. Major limitations and knowledge gaps in the literature are listed below:

i. Artificial macropores used in the literature are not comparable with the natural macropores with respect to physico-chemical and biochemical processes and interactions.
ii. Natural macropores have varying aperture, considerable tortuosity, and heterogeneous conditions throughout the length. These are absent in the artificially created macropores.
iii. Studies on biogeochemical reactions in the PFPs are rare. Dynamics of microbial processes in the PFPs have not been established.
iv. Response of the PFPs under water-stressed conditions (drought) will be a global challenge

To address some of these research gaps, overall objective of this proposal is set to characterise the preferential transport and degradation of nutrients and pesticides, and transport of bacteria through the macropores created by the root network of the plants. The specific objectives are as follows:

(i) Experimental investigation to characterise the enhanced transport of nutrients, pesticides and bacteria through the preferential flow paths created by the roots using artificial analogue and natural root network vis-à-vis soil matrix without the plant root network. Investigations will be carried out in the controlled environment of a growth chamber and in natural environment.

(ii) Calibrate a dual permeability flow model using the data from the experiments conducted in the controlled environment.

(iii) Formulate and calibrate a composite two-zone reactive transport model for nutrients, pesticides and bacteria through the root zone soil using the data from the experiments conducted in the controlled environment.

(iv) Validate the flow and transport models using the field experiments.

To make the study relevant to the context of the field application, we will conduct the experiments with two pesticides, (a) Chlorpyrifos, the most commonly used insecticide in Indian agriculture [Nayak and Solanki (2021)]; (b) Regent GR, a phenylpyrazole insecticide commonly used in the crops. For bacterial transport, we shall use *Escherichia Coli*, the most commonly used analogue for the microbial transport experiments and also an indicator organism for pathogens. For nutrients, we will use the commonly used fertilisers such as, Urea and DAP.

2.4. If the project is location specific, basis for selection of location be highlighted:

This project is not location specific.

3. Work Plan:

3.1. Methodology:

To meet the above objectives, following tasks will be accomplished:

3.1.1. Task 1: Literature Review:

The existing methods of water extraction from roots will be thoroughly studied. In addition to this, we also need to understand the recent advancements in the field of enumeration of bacterial species and the methodology for quantifying the bacterial activities inside the soil.

3.1.2. Task 2: Experimental Setup:

The experiments for the natural root system will be conducted in pots for the controlled environment in the growth chamber and in an existing experimental plot in the field. The experimental plot will have micro-lysimeter. Similar to Buttle and Leigh (1997), our set up will be equipped with soil moisture sensors, tensiometers and lysimeter suction cups to collect pore water samples. Target crops will include wheat or maize and a legume such as, Arhar. Several replicates will be setup at the beginning. Known volume of water containing nutrients, pesticides and E Coli will be applied at the surface. Leachate will be collected at the bottom of the pots and the lysimeters. Horizontal and vertical transects of the root zone will be taken and samples will be collected from macropores and the soil matrix. The samples will be analysed for nutrients, pesticides and bacteria. Macropore network will be characterised using dye tracers. The experiments will be conducted with plants of different ages. Multiple replicates will be conducted for every set of experiment to characterise the uncertainty. Dispersion will be characterised using a conservative tracer Lithium Chloride.

3.1.3. Task 3: Sample processing and analysis

The nutrients will be extracted and analysed in the ion chromatograph (Metrohm Inc.). The pesticide will be extracted using Soxhlet technique and analysed in an ion-trap GCMS (Polaris-Q, Thermo-Fisher). E-coli population will be assessed using MPN and microbial protein. Biodiversity will be analysed using DGGE for which, the samples will be sent to one of the national laboratories, e.g. IMTech, ARI, etc.

3.1.4. Task 4: Modeling of Flow and Transport

To model the flow through soil matrix and PFPs a dual-permeability model will be used (Gerke and van Genuchten, 1993). The dual-permeability model will be based on the mixed form of the Richards equation for both the soil matrix and PFPs and will allow for inter mass transfer. The parameters of the dual-permeability model will be obtained using calibration. Further, a composite two-zone reactive transport model will be formulated for nutrients, pesticides and bacteria transport through the root zone soil using the data from the experiments. The developed models will be validated with field-experiments at an existing agricultural site at IIT Kanpur. Soil hydraulic properties, hydro-meteorological parameters, and nutrients, pesticides and bacteria concentrations will be measured regularly in the field-site.

3.2. Time Schedule of activities giving milestones through BAR diagram

Tasks	Activities	Project time in months					
		6	12	18	24	30	36
Task 1	**Literature review**						
Task 2	**Procurement of Equipment**						
	Experimental Set up Design						
	Lab and field experiments						
Task 3	**Sample processing and analysis**						
Task 4	**Calibration of dual-permeability model**						
	Development and calibration of two-zone transport model						
	Validation of flow and transport models						
Task 5	**Reports and Publications**						

3.3. Suggested Plan of action for utilization of research outcome expected from the project.

Several avenues can be explored to extend this work.

(b) The transport model can be used to optimise the use of fertilisers in agricultural fields.

(c) The transport model can be used to assess the potential for contamination of the aquifers by the nutrients, pesticides and pathogens applied on the surface, due to preferential transport through the root network.

3.4. Environmental impact assessment and risk analysis

i. E-Coli will be hazardous to the environment, but we will Autoclave it before disposing it off.
ii. Apart from chemicals used in the laboratory, there should not be any environmental hazards.

4. Expertise:

4.1. Expertise available with the investigators in executing the project:

The PI's general research interest is in the area fate and transport of contaminants and microbes in the natural systems. In the past, the PI has been involved in both, experimental investigation and natural systems modelling at field and lab scales. Recent interest lies in the area of subsurface hydrology and contaminant transport with focusses on optimization of agricultural practices for water and pesticide uses, contamination of aquifers from surface processes and using natural isotopes to understand the subsurface hydrologic processes.

The Co-PI's research interest lies in modelling flow in vadose zone. In recent years, she along with her team members has been investigating the effect of variability in soil hydraulic properties on water movement in agricultural fields. In this project, the PI plans to utilize the knowledge she has acquired to study flow of water in preferential flow pathways.

4.2. Summary of roles/responsibilities for all investigators:

Sr. No.	Name of Investigators	Roles/Responsibilities
1	Saumyen Guha	Design and analysis of experiments, and modelling transport through PFPs
2	Richa Ojha	Design and analysis of experiments, modelling flow through PFPs

4.3. Key publications published by the Investigators pertaining to the theme of the proposal during the last 5 years.

Richa Ojha

1. E. Yetbarek, and R. Ojha (2021), Experimental evaluation of different sub-surface water movement models in an agricultural field with soil heterogeneity. *Journal of Hydrology*, 599, 1-15.
2. E. Yetbarek, S. Kumar, and R. Ojha (2020), Effects of soil heterogeneity on subsurface water movement in agricultural fields: A numerical study. *Journal of Hydrology*, 590, 1-15.
3. S. Kumar, E. Yetbarek, and R. Ojha (2020), Numerical Investigation of streamtube approach to model flow in heterogeneous unsaturated soils. *Journal of Hydrology*, 590, 1-12.
4. E. Yetbarek, and R. Ojha (2020). Spatio-temporal variability of soil moisture in a cropped agricultural plot within the Ganga Basin, India. *Agricultural Water Management*, 234, 106108.
5. R. Ojha, C. Corradini, R. Morbidelli, and R.S. Govindaraju (2017). Effective saturated conductivity for representing field-scale infiltration and surface soil moisture in heterogeneous unsaturated soils subjected to rainfall events, *Water* , 9(2), 134; doi:10.3390/w9020134.
6. Singh S. P., Guha S. and Bose P. (2017). Impact of the Composition of the Bacterial Population and Additional Carbon Source on Pathway and Kinetics of Degradation of Endosulfan Isomers, ***Environmental Science Processes & Impacts***, Vol. 19, No. 7, pp 964-974. https://doi.org/10.1039/C7EM00154A
7. Singh S. P., Guha S., Bose P. and Kunnikuruvan S. (2017). Mechanism of the hydrolysis of Endosulfan isomers, ***J. Phys. Chem. A***, Vol. 121, No. 27, pp5156-5163. https://doi.org/10.1021/acs.jpca.7b02012

4.4. Bibliography

1) Abu-Ashour, J., Joy, D.M., Lee, H., Whiteley, H.R., & Zelin, S. (1998). MOVEMENT OF BACTERIA IN UNSATURATED SOIL COLUMNS WITH MACROPORES. *Transactions of the ASABE, 41,* 1043-1050.

2) Akay, O., & Fox, G. A. (2007). Experimental Investigation of Direct Connectivity between Macropores and Subsurface Drains during Infiltration. *Soil Science Society of America Journal*, *71*(5), 1600–1606. https://doi.org/10.2136/sssaj2006.0359
3) Allaire-Leung, S. E., Gupta, S. C., & Moncrief, J. F. (2000a). Water and solute movement in soil as influenced by macropore characteristics 1. Macropore continuity. In *Journal of Contaminant Hydrology* (Vol. 41). www.elsevier.comrlocaterjconhyd
4) Allaire-Leung, S. E., Gupta, S. C., & Moncrief, J. F. (2000b). Water and solute movement in soil as influenced by macropore characteristics 2. Macropore tortuosity. In *Journal of Contaminant Hydrology* (Vol. 41). www.elsevier.comrlocaterjconhyd
5) Arora, B., Dwivedi, D., Faybishenko, B., Jana, R. B., & Wainwright, H. M. (2019). Understanding and Predicting Vadose Zone Processes. In *Reviews in Mineralogy and Geochemistry* (Vol. 85, pp. 303–328). Mineralogical Society of America. https://doi.org/10.2138/rmg.2019.85.10
6) Atkinson, J. A., Hawkesford, M. J., Whalley, W. R., Zhou, H., & Mooney, S. J. (2020). Soil strength influences wheat root interactions with soil macropores. *Plant Cell and Environment*, *43*(1), 235–245. https://doi.org/10.1111/pce.13659
7) Bauke, S. L., Landl, M., Koch, M., Hofmann, D., Nagel, K. A., Siebers, N., Schnepf, A., & Amelung, W. (2017). Macropore effects on phosphorus acquisition by wheat roots – a rhizotron study. *Plant and Soil*, *416*(1–2), 67–82. https://doi.org/10.1007/s11104-017-3194-0
8) Buttlea, J. M., & Leigh, D. G. (1997). The influence of artificial macropores on water and solute transport in laboratory soil columns. In *J.M. Bunle, D.G. LeigNJoumal of Hydrology* (Vol. 191).
9) Colombi, T., Braun, S., Keller, T., & Walter, A. (2017). Artificial macropores attract crop roots and enhance plant productivity on compacted soils. *Science of the Total Environment*, *574*, 1283–1293. https://doi.org/10.1016/j.scitotenv.2016.07.194
10) Cortés, J. A., Díez, L., Cañete, F. J., Sánchez-Martínez, J. J., & Entrambasaguas, J. T. (2011). Performance analysis of OFDM modulation on indoor broadband PLC channels. *Eurasip Journal on Advances in Signal Processing*, *2011*. https://doi.org/10.1186/1687-6180-2011-78
11) Franklin, S. M., Kravchenko, A. N., Vargas, R., Vasilas, B., Fuhrmann, J. J., & Jin, Y. (2021). The unexplored role of preferential flow in soil carbon dynamics. In *Soil Biology and Biochemistry* (Vol. 161). Elsevier Ltd. https://doi.org/10.1016/j.soilbio.2021.108398
12) Franklin, S., Vasilas, B., & Jin, Y. (2019). More than Meets the Dye: Evaluating Preferential Flow Paths as Microbial Hotspots. *Vadose Zone Journal*, *18*(1), 1–8. https://doi.org/10.2136/vzj2019.03.0024
13) Gerke, H. H., & van Genuchten, M. Th., (1993). A dual-porosity model for simulating the preferential movement of water and solutes in structured porous media. *Water Resour. Res*. 29, 305-319.
14) Germer, K., & Braun, J. (2015). Macropore-Matrix Water Flow Interaction around a Vertical Macropore Embedded in Fine Sand-Laboratory Investigations. *Vadose Zone Journal*, *14*(7), vzj2014.03.0030. https://doi.org/10.2136/vzj2014.03.0030
15) Gjettermann, B., Hansen, H. C. B., Jensen, H. E., & Hansen, S. (2004). Transport of Phosphate through Artificial Macropores during Film and Pulse Flow. *Journal of Environmental Quality*, *33*(6), 2263–2271. https://doi.org/10.2134/jeq2004.2263
16) Lamy, E., Lassabatere, L., Bechet, B., & Andrieu, H. (2009). Modeling the influence of an artificial macropore in sandy columns on flow and solute transfer. *Journal of Hydrology*, *376*(3–4), 392–402. https://doi.org/10.1016/j.jhydrol.2009.07.048
17) Larsbo, M., Koestel, J., Kätterer, T., & Jarvis, N. (2016). Preferential Transport in Macropores is Reduced by Soil Organic Carbon. *Vadose Zone Journal*, *15*(9), vzj2016.03.0021. https://doi.org/10.2136/vzj2016.03.0021
18) Li, Y., & Ghodrati, M. (n.d.). *Preferential Transport of Nitrate through Soil Columns Containing Root Channels*.
19) Mori, Y., & Hirai, Y. (2014). Effective Vertical Solute Transport in Soils by Artificial Macropore System. *Journal of Hazardous, Toxic, and Radioactive Waste*, *18*(2). https://doi.org/10.1061/(asce)hz.2153-5515.0000192
20) Nakamoto, T. (1997). The Distribution of Maize Roots as Influenced by Artificial Vertical Macropores. *Japanese Journal of Crop Science, 66,* 331-332.
21) Nimmo, J. R. (2021). The processes of preferential flow in the unsaturated zone. In *Soil Science Society of America Journal* (Vol. 85, Issue 1, pp. 1–27). John Wiley and Sons Inc. https://doi.org/10.1002/saj2.20143
22) Pruess, K. (1998). On water seepage and fast preferential flow in heterogeneous, unsaturated rock fractures. In *Pruessr Journal of Contaminant Hydrology* (Vol. 30).
23) Šimůnek, J., van Genuchten, M.T. and Šejna, M. (2008), Development and Applications of the HYDRUS and STANMOD Software Packages and Related Codes. Vadose Zone Journal, 7: 587-600. https://doi.org/10.2136/vzj2007.0077

24) Šimůnek, J., van Genuchten, M.T. and Šejna, M. (2016), Recent Developments and Applications of the HYDRUS Computer Software Packages. Vadose Zone Journal, 15: 1-25 vzj2016.04.0033. https://doi.org/10.2136/vzj2016.04.0033
25) Tofteng C., Hansen S., Jensen H. E.; Film and Pulse Flow in Artificial Macropores. *Hydrology Research* 1 August 2002; 33 (4): 263–274. doi: https://doi.org/10.2166/nh.2002.0007
26) Valenzuela, F. J., Reineke, D., Leventini, D., Chen, C. C. L., Barrett-Lennard, E. G., Colmer, T. D., Dodd, I. C., Shabala, S., Brown, P., & Bazihizina, N. (2022). Plant responses to heterogeneous salinity: agronomic relevance and research priorities. In *Annals of Botany* (Vol. 129, Issue 5, pp. 499–518). Oxford University Press. https://doi.org/10.1093/aob/mcac022
27) Xiong, P., Zhang, Z., Guo, Z., & Peng, X. (2022). Macropores in a compacted soil impact maize growth at the seedling stage: Effects of pore diameter and density. *Soil and Tillage Research*, *220*. https://doi.org/10.1016/j.still.2022.105370
28) Zhang, Y., Zhang, R., Zhang, B., & Xi, X. (2021). Artificialmacropores with sandy fillings enhance desalinization and increase plant biomass in two contrasting salt-affected soils. *Applied Sciences (Switzerland)*, *11*(7). https://doi.org/10.3390/app11073037
29) Zhou, B. B., Li, Y., Wang, Q. J., Jiang, Y. L., & Li, S. (2013). Preferential water and solute transport through sandy soil containing artificial macropores. *Environmental Earth Sciences*, *70*(5), 2371–2379. https://doi.org/10.1007/s12665-013-2339-6

5. List of projects submitted/implemented by the Investigators.

5.4. Details of Projects submitted to various funding agencies: NIL

Sr. No.	Title	Cost in Lakh	Month of submission	Role as PI/Co-PI	Agency	Status

5.5. Details of Projects under implementation:

Sr. No.	Title	Cost in Lakh	Start Date	End Date	Role as PI/Co-PI	Agency
Richa Ojha						
1	Temporal variability of soil hydraulic properties in agricultural fields	67.5	Dec, 2021	Dec, 2024	PI	SERB
2	Estimation of effective soil hydraulic properties of macropores in soils using surface soil moisture observations	54	Aug, 2021	Aug, 2024	PI	MOES
3	Partitioning Evapotranspiration into Evaporation and Transpiration Fluxes using Isotopes of Oxygen and Hydrogen	80	Mar, 2021	Mar, 2024	Co-PI	SERB
Saumyen Guha						
1.	Partitioning Evapotranspiration into Evaporation and Transpiration Fluxes using Isotopes of	80 lakhs	Mar, 2021	Mar, 2024	Co-PI	SERB

	Oxygen and Hydrogen					
2.	Analysis and Process Modification of CETP at Ankleshwar	4.1 crores	Apr 2008	Mar 2024	PI	BEIL, UPL

5.6. Details of Projects completed during last 5 years:

Sr. No.	Title	Cost in Lakh	Start Date	End Date	Role as PI/Co-PI	Agency
Richa Ojha						
1	Numerical and experimental investigation of water movement under heterogeneous condition in unsaturated soils	54	Oct, 2016	Mar, 2020	PI	SERB
Saumyen Guha						
1.	Bioreactor for Simultaneous Removal of Fine Particulate Matter and Volatile Organic Carbon from Flue Gas	32.15 lakhs	July 2018	Oct 2022	PI	DST - WOSA
2.	Optimization of a Photobioreactor for Tertiary Treatment of Secondary Treated Sewage and Triglyceride Content in Algae for Production of Aviation Turbine Fuel	19.2 lakhs	Apr 2017	Mar 2019	PI	SERB-NPDF

6. List of facilities being extended by parent institution(s) for the project implementation.

6.4. Infrastructure Facilities

Sr. No.	Infrastructural Facility	Yes/No/Not required Full or sharing basis
1	Workshop Facility	Yes
2	Water and Electricity	Yes
3	Laboratory Space/Furniture	Yes
4	Power Generator	Yes
5	AC Room or AC	Yes
6	Telecommunication including e-mail & fax	Yes
7	Transportation	No

8	Administrative/Secretarial support	Yes
9	Information facilities like Internet/Library	Yes
10	Computational facilities	Yes
11	Animal/Glass House	Not required
12	Any other special facility being provided	No

6.5. Equipment available (Relevant to this project) with the Institute/Group/Department for the project:

Equipment available with	Generic Name of Equipment	Model, Make and year of purchase	Remarks including accessories available and current usage of equipment
PI and his group	Ion-Trap GCMS	Polaris-Q, Thermo-Fisher, 2006	Available for usage in this project with all required accessories
	Ion Chromatograph	Model 925, Metrohm, 2023	-do-
	UV-Vis Spectrophotometer	Cary-60, Varian, 2016	-do-
	Microscope	BX-53, Olympus, 2023	-do-
	Precision Balance	Sartorius, 2016	-do-
	HACH Water Quality	HQ40d, HACH, 2017	-do-
	Rotary evaporator	R-100, Buchi, 2019	-do-

- Computer Center (CC): The institute has a state-of-the-art computer center which is equipped with ultra modern computing facilities for teaching and research. The CC provides various advance and special purpose software for all the campus users.
- Hydraulics and Hydrology, Geotechnical, and Environmental Laboratory: The laboratory has oven, rainfall simulator, constant head, WP4C, permeameter, pressure plate apparatus, laminar flow hoot, incubators, anaerobic glove box, centrifuge, fume hood, Soxhlet extraction setup and other usual wet laboratory setups. The local scale experiments proposed in the project will be conducted in these labs.
-

7. Name and address of experts/institution interested in the subject/outcome of the project.

Prof. B. S. Murty, Department of Civil Engineering, IIT Madras, Chennai - 600 036, Tamil Nadu, India

Prof. Ligy Philip, Department of Civil Engineering, IIT Madras, Chennai - 600 036, Tamil Nadu, India

Prof. Manoj K. Tiwari, School of Water Resources, IIT Kharagpur, West Bengal, 721302

Budget Details

Institution wise Budget Breakup :

Budget Head	Indian Institute of Technology Kanpur	Total
Research Personnel	12,63,600	**12,63,600**
Consumables	18,75,000	**18,75,000**
Travel	2,00,000	**2,00,000**
Equipment	14,50,000	**14,50,000**
Contingencies	1,80,000	**1,80,000**
Overhead	9,93,720	**9,93,720**
Total	**59,62,320**	**59,62,320**

Institute Name : *Indian Institute of Technology Kanpur*

Year Wise Budget Summary (Amount in INR) :

Budget Head	Year-1	Year-2	Year-3	Total
Research Personnel	3,88,800	4,21,200	4,53,600	**12,63,600**
Consumables	8,35,000	6,12,000	4,28,000	**18,75,000**
Travel	0	1,00,000	1,00,000	**2,00,000**
Equipments	14,50,000	0	0	**14,50,000**
Contingencies	60,000	60,000	60,000	**1,80,000**
Overhead	5,46,760	2,38,640	2,08,320	**9,93,720**
Grand Total	**32,80,560**	**14,31,840**	**12,49,920**	**59,62,320**

Research Personnel Budget Detail (Amount in INR) :

Designation	Year-1	Year-2	Year-3	Total
Senior Research Fellow *One person with MTech in Water Resources Area will be required to carry out the work proposed*	3,88,800	4,21,200	4,53,600	**12,63,600**

Consumable Budget Detail (Amount in INR) :

Justification	Year-1	Year-2	Year-3	Total
Year 1: growth chamber expt setup with suction lysimeters; consumables for protein analysis, Soxhlet; growth media; standards and solvent for IC and GCMS; DGGE paid analysis *Year 2: field expt setup with lysimeters; consumables for protein analysis, Soxhlet; growth media; standards and solvent for IC and GCMS; DGGE paid analysis* *Year 3: field expt consumables; consumables for protein analysis, Soxhlet; growth media; standards and solvent for IC and GCMS; DGGE paid analysis*	8,35,000	6,12,000	4,28,000	**18,75,000**

Travel Budget Detail (Amount in INR) :

Justification (Inland Travel)	Year-1	Year-2	Year-3	Total
Year 1: No travel necessary *Year 2: Presenting results in national conferences, travel support for SRF, PI and Co-PI* *Year 2: Presenting results in national conferences, travel support for SRF, PI and Co-PI*	0	1,00,000	1,00,000	**2,00,000**

Equipment Budget Detail (Amount in INR) :

Generic Name ,Model No. , (Make)/ Justification	Quantity	Spare time	Estimated Cost
Datalogger ZI6 (Meter Group) *The soil moisture sensors will be connected to the data loggers for continuous collection of data from the field experiments. These will also be used with the tensiometers.*	3	0 %	**1,80,000**
Automated Kjeldahl Nitrogen Digester cum distiller KBD060 KDI040 (Borosil) *Nutrient analysis is a key component in the proposal. Large number of samples have to be analysed for TKN. This unit will be able to digest the sample in a routine manner for subsequent analysis in the ion chromatograph.*	1	20 %	**5,00,000**
Plant Growth Chamber PGC-175 (Bionics) *Plant growth chamber is required for setting the control experiments.*	1	20 %	**3,20,000**
Soil moisture sensor Teros10 (Meter Group) *Soil moisture sensors are required for the field experiments. Each lysimeter will be equipped with 4 sensors. They will be connected to a data logger for continuous data collection.*	12	20 %	**2,70,000**
Tensiometer Teros31 (Meter Group) *Tensiometers are required for both, controlled environment and field experiments. They will be used by rotation in different setups.*	4	0 %	**1,80,000**

Contingency Budget Detail (Amount in INR) :

Justification	Year-1	Year-2	Year-3	Total
This budget is primarily for the sporadic daily labor required for help with farming, soil handling, planting and watering. Other stationary supplies will also be covered with this.	60,000	60,000	60,000	**1,80,000**

Overhead Budget Detail (Amount in INR) :

Justification	Year-1	Year-2	Year-3	Total
IIT Kanpur charges an overhead of 20% of the total budgeted amount for all research projects.	5,46,760	2,38,640	2,08,320	**9,93,720**

BIO-DATA

1. Name and full correspondence address: Saumyen Guha
Department of Civil Engineering
Indian Institute of Technology Kanpur
Kanpur, UP 208016

2. Email(s) and contact number(s): sguha@iitk.ac.in, +91 512 259 7917

3. Institution: Indian Institute of Technology Kanpur

4. Date of Birth: Nov 01, 1966

5. Gender (M/F/T): Male

6. Category Gen/SC/ST/OBC: General

7. Whether differently abled (Yes/No): No

8. Academic Qualification (Undergraduate Onwards)

S. No.	Degree	Year	Subject	University	% of marks
1.	PhD	1996	Civil Engineering and Operations Research	Princeton University	Numercal Grade or Marks Not Awarded
2.	M. Tech.	1989	Civil Engineering	IIT Kanpur	9.47/10.0
3.	B.E.	1987	Civil Engineering	University of Calcutta (Bengal Engineering College)	79.04%

9. Ph.D thesis title, Guide's Name, Institute/Organisation/University, Year of Award

Title: *Surfactant Enhanced Bioremediation: Bioavailability of Hydrophobic Organic Compounds Partitioned into the Micellar Phase of Nonionic Surfactants*
Guide's Name: Peter Jaffe
University: Princetion University
Year of Award: 1996

10. Work Experience (in chronological order)

S. No.	Positions Held	Name of the Institute	From	To	Payscale (per month)
1.	Research Associate	IIT Kanpur	Apr. 1989	July 1989	Rs. 1200
2.	Sr. Research Associate	IIT Kanpur	Aug 1989	July 1990	Rs. 1800
3.	Post Doctoral Research Associate	Princeton University	Nov. 1995	Aug. 1997	US$ 4000
4.	Assistant Professor	IIT Kanpur	Oct. 1997	Oct. 2003	Rs. 3700-5700
5.	Associate Professor	IIT Kanpur	Nov 2003	Nov 2010	Rs. 37,400 – 67,000
6.	Visiting Professor (on Sabbatical from IITK)	University of Regina	Aug 2006	Dec 2006	Can $ 7500 (Hon)

7.	Professor	IIT Kanpur	Nov 2010	At present	Rs. 1,59,100-2,20,200

11. Professional Recognition/ Award/ Prize/ Certificate, Fellowship received by the applicant

Nil

12. Publications (Select list of papers published in SCI journals that are relevant to the subject of this proposal, i.e., reactive transport in natural systems, pesticides, metals, nutrients)

S.No.	Author(s)	Title	Name of Journal	Volume	Page	Year
1.	Singh S. P., Guha S. and Bose P.	Impact of the Composition of the Bacterial Population and Additional Carbon Source on Pathway and Kinetics of Degradation of Endosulfan Isomers	***Environmental Science Processes & Impacts***	19	964	2017
2.	Singh S. P., Guha S., Bose P. and Kunnikuruvan S.	Mechanism of the hydrolysis of Endosulfan isomers	***J. Phys. Chem. A***	121	5156	2017
3.	Tiwari M. K., and Guha S.	Kinetics of biotransformation of chlorpyrifos in aqueous and soil slurry environments	Water Research	51	73	2014
4.	Tiwari M. K., and Guha S.	Kinetics of the biodegradation pathway of endosulfan in the aerobic and anaerobic environments	Chemosphere	93	567	2013
5.	Singh S. P., Bose P., Guha S., Gurjar S. K. and Bhalekar, S.	Impact of addition of amendments on the degradation of DDT and its residues partitioned on soil	Chemosphere	92	811	2013
6.	Tiwari M. K., and Guha S.	Simultaneous analysis of endosulfan, chlorpyrifos and their metabolites in natural soil and water samples using gas chromatography-tandem mass spectrometry	***Environ. Monitoring. Assessement***	185	8451	2013
7.	Tiwari M. K., and Guha S.	Role of Soil Organic Matter on Sorption and Cosorption of Endosulfan and Chlorpyrifos on Agricultural Soils	***J. Env. Eng., ASCE***	138	426	2012
8.	Guha S.; Raymahashay B. C.; Banerjee A.; Acharyya S. K.; Gupta, A.	Collection of Depth-Specific Groundwater Samples from an Arsenic Contaminated Aquifer in West Bengal, India	***Environ. Eng. Sci.***	22	870	2005

9.	Acharyya S. K., Chakraborty P., Lahiri S., Raymahashay B. C., Guha S. and Bhowmik A.	Arsenic Poisoning in the Ganges Delta	Nature	401	545	1999

13. Detail of patents

Nil

14. Books/Reports/Chapters/General articles etc. (relevant to this proposal)

S. No.	Title	Author's Name	Publisher	Year of Publication
1.	*Numerical Methods for Engineering and Science*	Guha S., Srivastava R.	Oxford University Press	2010
2.	Dealing with draught: Issues for implementation, in *India Infrastructure Report (IIR)*,	Guha S.	Oxford University Press	2001

15. Any other information (maximum 500 words)

Advisor, International Foundation for Science (IFS), Stockholm, Sweden. (2008 onwards)

Principal Investigator of the *Wastewater Treatment and Management* (WWTM) project of *Asian Regional Research Programme in Environmental Technology* (ARRPET) funded by Sida, Sweden 2000-08. Out of four PIs in the ARRPET, I was the only one chosen outside the coordinating institute of AIT. The WWTM project consisted of five sub-projects involving *National Research Institutes* (NRIs) from Thailand, Vietnam and India. My role included co-ordination and management of the activities of these five institutes. Review report of the project is available at https://www.sida.se/contentassets/f3569933ba5d4ac4b105a3d66476ed3e/200827-the-asian-regional-research-programme-on-environmental-technologies-arrpet_1932.pdf

Member of selection committees at IIT Bombay, IIT Madras, IIT (ISM) Dhanbad, IIT Roorkee, IIT Jodhpur, and IIEST Shibpur.

Member of National Review Committee for the Department of Civil Engineering at IIT Hyderabad and Department of Environmental Engineering at IIT (ISM) Dhanbad

Advisor for Sustainable Water Management at IIT(ISM) Dhanbad (2019 onwards).

BIO-DATA

1. Name and full correspondence address: Richa Ojha
Department of Civil Engineering,
Indian Institute of Technology, Kanpur
Uttar Pradesh-208016

2. Email(s) and contact number(s): richao@iitk.ac.in; +91 512 679 6564

3. Institution: Indian Institute of Technology, Kanpur

4. Date of Birth: 18th November, 1985

5. Gender (M/F/T): Female

6. Category Gen/SC/ST/OBC: General

7. Whether differently abled (Yes/No): No

8. Academic Qualification (Undergraduate Onwards)

S No.	Degree	Year	Subject	University/ Institution	% of marks
1	Ph.D.	2014	Civil Engineering	Purdue University	CPI: 4.00/4.00
2	M.E.	2011	Civil Engineering	Indian Institute of Sciences, Bangalore	CPI: 7.80/8.00
3	B. Tech.	2008	Civil Engineering	G.B.P.U.A & Technology, Pantnagar, Uttarakhand	CPI: 8.62/10.00

9. Ph.D thesis title, Guide’s Name, Institute/Organization/University, Year of Award.

Title: Scaling of surface soil moisture and solute movement from local- to field-scale in unsaturated soils
Guide's Name: Prof. Rao S. Govindaraju
Institute: Purdue University, USA
Year of Award: 2014

10. Work experience (in chronological order).

S No.	Positions held	Name of the institute	From	To	Payscale
1	Graduate Engineer Trainee	Larsen and Toubro ECC division	July, 2008	June, 2009	Rs 18,500

2	Assistant Professor	Department of Civil Engineering, I.I.T. Kanpur	16th Feb, 2015 onwards		Rs 1,31,400-2,04,700

11. Professional Recognition/ Award/ Prize/ Certificate, Fellowship received by the applicant.

S No.	Name of the award	Award Agency	Year
1	NASI Young Scientist Platinum Jubilee Award	The National Academy of Sciences, India	2020
2	Early Career Research Award	SERB, India	2016
3	ASCE State of the Art Civil Engineering Award	ASCE, USA	2016
4	Civil Engineering Best Dissertation Award	Purdue University	2014
5	Jacques W. Delleur Award	Purdue University	2013
6	Ross Fellowship	Purdue University	2011-2014
7	Prof. N. S. Govinda Rao Memorial Gold Medal	Indian Institute of Science, Bangalore	2011
8	Practicum Exchange Program Fellowship	University of New South Wales, Australia	2010

12. Publications *(List of papers published in SCI Journals, in year wise descending order).*

S.No.	Author(s)	Title	Name of Journal	Volume	Page	Year
1	Ephrem Yetbarek, Saurabh Kumar, and Richa Ojha	Effects of soil heterogeneity on subsurface water movement in agricultural fields: A numerical study.	Journal of Hydrology	590	125420	2020
2	Saurabh Kumar, Ephrem Yetbarek, and Richa Ojha	Numerical investigation of streamtube approach to model flow in heterogeneous unsaturated sandy soils.	Journal of Hydrology	590	125250	2020

S.No.	Author(s)	Title	Name of Journal	Volume	Page	Year
3	Ephrem Yetbarek, and Richa Ojha	Spatio-temporal variability of soil moisture in a cropped agricultural plot within the Ganga Basin, India.	Agricultural Water Management	234	106108	2020
4	Richa Ojha	Identification of homogeneous regions of near surface air temperature lapse rates across India.	International Journal of Climatology	39(11)	4288-4304	2019
5	Richa Ojha and Shivam Tripathi	Using attributes of ungauged basins to improve regional regression equations for flood estimation: a deep learning approach.	ISH Journal of Hydraulic Engineering	24(2)	239-248	2018
6	Richa Ojha, C. Corradini, R. Morbidelli, and Rao S. Govindaraju	Effective saturated hydraulic conductivity for representing field-scale infiltration and surface soil moisture in heterogeneous unsaturated soils subjected to rainfall events	Water			2017
7	Richa Ojha	Assessing seasonal variation of near surface air temperature lapse rate across India	International Journal of Climatology		1-14	2016

S.No.	Author(s)	Title	Name of Journal	Volume	Page	Year
8	Richa Ojha and Rao S. Govindaraju,	A Physical Scaling Model for Aggregation and Disaggregation of Field-Scale Surface Soil Moisture Dynamics	Chaos: An Interdisciplinary Journal of Nonlinear Science	25	1-14	2015
9	Richa Ojha, A. Prakash, C. Corradini, R. Morbidelli, and Rao S. Govindaraju	Temporal Moment Analysis for Stochastic-Advective Vertical Solute Transport in Heterogeneous Unsaturated Soils	Journal of Hydrology	521	261-273	2015
10	M. Ramadas, R. Maity, R. Ojha, and Rao S. Govindaraju	Predictor Selection for Streamflow Using a Graphical Modeling Approach	Stochastic Environmental Research and Risk Assessment	29	1583-1599	2014
11	Richa Ojha, A. Prakash, and Rao S. Govindaraju	Local- and Field-Scale Stochastic-Advective Vertical Solute Transport in Horizontally Heterogeneous Unsaturated Soils	Water Resources Research	50	6658-6678	2014
12	Richa Ojha, R. Morbidelli, C. Saltalippi, A. Flammini, and Rao S. Govindaraju	Scaling of Surface Soil Moisture over Heterogeneous Fields Subjected to a Single Rainfall Event	Journal of Hydrology	516	21-36	2014
13	Richa Ojha, D. Nagesh Kumar, A. Sharma, and R.Mehrotra	Assessing GCM Convergence for the Indian Region Using the Variable Convergence Score.	ASCE Journal of Hydrologic Engineering,	19	1237-1246	2014

S.No.	Author(s)	Title	Name of Journal	Volume	Page	Year
14	Richa Ojha, M. Ramadas, and R. S. Govindaraju,	Current and Future Challenges in Groundwater I. Modeling and Management of Resources.	ASCE Journal of Hydrologic Engineering.	20	1-21	2013
15	M. Ramadas, Richa Ojha and R. S. Govindaraju,	Current and Future Challenges in Groundwater II. Water Quality Modeling.	ASCE Journal of Hydrologic Engineering.	20	2-24	2013
16	Richa Ojha, D. Nagesh Kumar, A. Sharma, and R.Mehrotra	Assessing Severe Drought and Wet Events over India in a Future Climate Using a Nested Bias-Correction Approach.	ASCE Journal of Hydrologic Engineering.	18	760-772	2013

13. Book Chapters

S.No.	Title	Author's Name	Publisher	Year of Publication
1	Monthly Variation in Near Surface Air Temperature Lapse Rate Across Ganga Basin, India.	Richa Ojha	In *The Ganga River Basin: A Hydrometeorological Approach* (pp. 149-160), Springer, Cham	2021
2	Numerical Analysis of Water Movement in Agricultural Fields with Heterogeneous Unsaturated Soils	Ephrem Yetbarek, and Richa Ojha	In Water Security and Sustainability (P 3-10), Springer	2019

S.No.	Title	Author's Name	Publisher	Year of Publication
3	Geospatial technologies for rainfall and atmospheric water measurement over arid regions of India.	K. Shukla, S. Shukla and Richa Ojha	In: Sustainable Water Resources Management, Pub : American Soc. Civil Engrs (ASCE), 263-292.	2017
4	Climate change pattern and its effect on hydrologic cycle: A review	R. Ojha, S. Pathak, P.K. Bhunya, S.K. Jain, and A. J. Adeloye	In Sustainable Water Resources Management, Pub : American Soc. Civil Engrs (ASCE), 293-316.	2017

14. Any other Information
    Conference Papers Published-19
    Member-ASCE, ISH
    Reviewer for National/International Journals

Undertaking by the Principal Investigator

To

The Secretary
SERB, New Delhi

Sir

I Saumyen Guha

herby certify that the research proposal titled Transport of Pesticides and Bacteria Through Macropores Created by Plant Root Network submitted for possible funding by SERB, New Delhi is my original idea and has not been copied/taken verbatim from anyone or from any other sources. I further certify that this proposal has been checked for plagiarism through a plagiarism detection tool i.e. Turnitin approved by the Institute and the contents are original and not copied/taken from any one or many other sources. I am aware of the UGCs Regulations on prevention of Plagiarism i.e. University Grant Commission (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulation, 2018. I also declare that there are no plagiarism charges established or pending against me in the last five years. If the funding agency notices any plagiarism or any other discrepancies in the above proposal of mine, I would abide by whatsoever action taken against me by SERB, as deemed necessary.

15/03/2023

Signature of PI with date

Name / designation

Saumyen Guha, Professor

Certificate from the Investigator

Project Title: Transport of Pesticides and Bacteria Through Macropores Created by Plant Root Network

It is certified that

1. The same project proposal has not been submitted elsewhere for financial support.

2. We/~~I~~ undertake that spare time on equipment procured in the project will be made available to other users.

3. We/~~I~~ agree to submit a certificate from Institutional Biosafety Committee, if the project involves the utilization of genetically engineered organisms. We/I also declare that while conducting experiments, the Biosafety Guidelines of Department of Biotechnology, Department of Health Research, GOI would be followed in toto.

4. We/~~I~~ agree to submit ethical clearance certificate from the concerned ethical committee, if the project involves field trails/experiments/exchange of specimens, human & animal materials etc.

5. The research work proposed in the scheme/project does not in any way duplicate the work already done or being carried out elsewhere on the subject.

6. We/~~I~~ agree to abide by the terms and conditions of SERB grant.

Name and signature of Principal Investigator: Saumyen Guha
Date: Mar 15, 2023
Place: Kanpur, UP

Name and signature of Co-PI (s) (if any): Richa Ojha
Date: Mar 15, 2023
Place: Kanpur, UP

भारतीय प्रौद्योगिकी संस्थान कानपुर
Indian Institute of Technology Kanpur
अधिष्ठाता अनुसंधान एवं विकास कार्यालय
DEAN OF RESEARCH & DEVELOPMENT (DORD) OFFICE

Endorsement from the Head of the Institution of PI

(To be given on University/ Institute/Organization/College Letter head)

This is to certify that:

1. Institute welcomes participation of Name : ...Saumyen Guha.......Designation : ....Professor..........as the Principal Investigator and ....Richa Ojha......................................as the Co- Investigator/s for the project titled Transport of Pesticides and Bacteria Through Macropores Created by Plant Root Network..................and that in the unforeseen event of discontinuance by the Principal Investigator, the Co-Investigator will assume the responsibility of the fruitful completion of the project with the approval of SERB.

2. The PI.....Saumyen Guha..........is a permanent or regular employee of this Institute/University/Organization and has ....9........ years of regular service left before superannuation

3. The project starts from the date on which the University/Institute/ Organization/College receives the grant from SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi.

4. The investigator will be governed by the rules and regulations of University/ Institute/Organization/College and will be under administrative control of the University/ Institute/Organization/College for the duration of the project.

5. The grant-in-aid by the SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi will be used to meet the expenditure on the project and for the period for which the project has been sanctioned as mentioned in the sanction order.

6. No administrative or other liability will be attached to SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi at the end of the project.

7. The University/Institute/Organization/College will provide basic infrastructure and other required facilities to the investigator for undertaking the research project.

8. The University/ Institute/Organization/College will take into its books all assets created in the above project and its disposal would be at the discretion of SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi.

9. The University/ Institute/Organization/College assumes to undertake the financial and other management responsibilities of the project.

Seal of

University/ Institute/Organization/College

अधिष्ठाता
DEAN
अनुसंधान एवं विकास
Research & Development
आई० आई० टी० कानपुर
I. I. T. KANPUR

Date: 13/03/2023

Signature Hcun

Registrar of University/Head of the Institute/
Head of organization / Principal of College

Endorsement from the Head of the Institution of Co-PI

(To be given on University/ Institute/Organization/College Letter head)

This is to certify that:

1. Institute welcomes participation of Name : Saumyen Guha Designation : Professor as the Principal Investigator and Richa Ojha as the Co- Investigator for the project titled Transport of Pesticides and Bacteria Through Macropores Created by Plant Root Network and that in the unforeseen event of discontinuance by the Principal Investigator, the Co-Investigator will assume the responsibility of the fruitful completion of the project with the approval of SERB.

2. The Co-PI, Richa Ojha is a permanent or regular employee of this Institute/University/Organization and has 28 years of regular service left before superannuation

3. The Co-PI will be governed by the rules and regulations of University/ Institute/Organization/College and will be under administrative control of the University/ Institute/Organization/College for the duration of the project.

4. The grant-in-aid by the SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi will be used to meet the expenditure on the project and for the period for which the project has been sanctioned as mentioned in the sanction order.

5. No administrative or other liability will be attached to SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi at the end of the project.

6. The University/Institute/Organization/College will provide basic infrastructure and other required facilities to the investigator for undertaking the research project.

7. The University/ Institute/Organization/College will take into its books all assets created in the above project and its disposal would be at the discretion of SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi.

8. The University/ Institute/Organization/College assumes to undertake the financial and other management responsibilities of the project.

Seal of University/ Institute/Organization/College

अधिष्ठाता
DEAN
अनुसंधान एवं विकास
Research & Development
आई० आई० टी० कानपुर
I. I. T. KANPUR

Signature

Registrar of University/Head of the Institute/ Head of organization / Principal of College

Date: 13/03/2023