ASIA-PACIFIC NETWORK FOR GLOBAL CHANGE RESEARCH

FINAL REPORT

Mapping groundwater resilience to climate change and human development in Asian cities

CRRP2018-01MY-SHRESTHA

2022

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1. Summary

Groundwater is ideally depicted as world's real hidden treasure, and it constitute 94% of the freshwater resources. Groundwater is the most desirable source of water supply, and it is less vulnerable to quality degradation and drought than surface water. Groundwater plays an important role in the sustainable development of major cities in Asia (Bangkok and its vicinity, Ho Chi Minh City, Lahore, and Kathmandu Valley). Importance of groundwater for the city's water supply will probably intensify under climate change and human development (population growth, urbanization) in the future. Therefore, it is imperative to assess the resiliency of groundwater under climate change and human development for strategic planning and management of water resources in urban areas. Mapping groundwater resilience to climate change and human development in Asian cities can be the efficient tools to analyse the area where the preventive measures are urgent and to understand the behaviour of groundwater system which ultimately helps in the management and protection of groundwater resources as well as to develop strategies for sustainable use. This study focusses on analysing the impact of climate change and human development (land-use change, population growth, change in abstraction) on groundwater resources and accessing the groundwater resiliency of Asian cities. This project first aims to develop robust framework to access the resiliency of groundwater system. The framework was developed using several parameters of resiliency. Then the framework was applied in four Asian cities (Bangkok and its vicinity, Ho Chi Minh City, Lahore, and Kathmandu Valley) to assess the resiliency of groundwater to climate change and human development.

2. Objectives

There are four key objectives:

1. To develop a framework for the assessment of resiliency of groundwater to climate change and human development in urban environment.
2. To assess the impact of climate change and human development on groundwater recharge and quality of four Asian cities.
3. To assess the resiliency of groundwater of four Asian cities to climate change and human development.
4. To develop evidence-based guidance on assessing how groundwater can support adaptation and build resilience to climate change.

These objectives will help to tackle following research questions:

1. How will the climate change in the study area?
2. How will the land use change in the study area?
3. How will the population and water demand change in the study area?
4. How will groundwater recharge change due to future climate change and land use change?
5. How will climate change, population growth, increased water demand and land use change impact future groundwater level?
6. What will be the future groundwater resiliency under climate change and human development scenarios?

3. Outputs, Outcomes, and Impacts

Outputs	Outcomes	Impacts
-Framework for assessing groundwater resilience to climate change and human development in Asian cities. -Climate change (under RCP 4.5 and RCP 8.5) and Land-use Change (under high, medium, and low urbanization scenarios) outlook of four Asian cities (Bangkok and its vicinity, Ho Chi Minh City, Kathmandu Valley, and Lahore). -Outlook of Water demand and groundwater abstraction forecasting under three urbanization scenarios of four Asian cities. -Record of impact of climate change and human development (land-use change and population growth) in groundwater recharge and groundwater level of Asian cities. -Resiliency of groundwater resources under climate change and human development in Asian cities. -Regional workshop completed	-Groundwater resilience indicators were developed and verified, which in turn were used to assess the groundwater resiliency of Asian cities. -Climate change and land use change outlook of Asian cities has been documented. -Water demand and groundwater abstraction under three urbanization scenarios of four Asian cities has been documented. -Climate change and land use change outlook and its impact on groundwater resources for four Asian cities has been published in high quality journal paper. -Resiliency of groundwater resources under climate change and human development in Asian cities has been documented. -Trained personnel	The results from this project provide insight knowledge on the behaviour of groundwater system and make people understand how groundwater respond to climate change and human development. All four Asian cities have been experiencing substantial loss of groundwater because of rapid population growth, rapid urbanization, tourism development, industrialization along with climate change. The large-scale groundwater extraction in both the cities lead to an adverse economic and environmental problems like continuous lowering of groundwater table, groundwater contamination and land subsidence. Therefore, there is a urgent need of immediate action to protect the groundwater resources. This can be achieved by developing adequate policies, strategies and legislation relating to groundwater management which includes groundwater licensing, pricing etc. to control the groundwater abstraction. This project urges the government authorities to establish an institutional framework characterized by leadership, sound organization and sufficient capacity for the sustainable management groundwater resources. Furthermore, this project provides some strategies for sustainable groundwater management which includes public awareness to reduce the groundwater uses, conjunctive use of surface and groundwater, use of Manage Aquifer Recharge techniques to improve recharge to the aquifers, improving groundwater governance and increasing collaboration with government, academia, and local people.

4. Key facts/figures

- Framework to assess groundwater resilience to climate change and human development on Asian cities have been produced.
- Three regional workshop (one in-person workshop and two hybrid workshop) on mapping groundwater resilience to climate change and human development on Asian cites have been held to disseminate the project findings to collaborators and participants.
- Six journal articles in high quality journal have been published.
- Five presentations on conference have been done.
- Project website has been developed.
- Four Thesis has been published including three master's thesis and one PhD thesis.
- Sixteen researchers from four different countries (Nepal, Thailand, Vietnam, and Pakistan) have been trained to assess the groundwater resiliency under climate change and human development in Asian cities.

5. Publications

1. Shrestha, S., Neupane, S., Mohanasundaram, S., & Pandey, V.P. (2020). Mapping groundwater resiliency under climate change scenarios: A case study of Kathmandu Valley, Nepal, Environmental Research, 183, 109149. https://doi.org/10.1016/j.envres.2020.109149

2. Adhikari, R.K., Mohanasundaram, S., & Shrestha, S. (2020). Impacts of land-use changes on the groundwater recharge in the Ho Chi Minh city, Vietnam. Environmental Research, 185, 109440. https://doi.org/10.1016/j.envres.2020.109440

3. Aslam, R. A., Shrestha, S., Pal, I., Ninsawat, S., Shanmugam, M. S., & Anwar, S. (2020). Projections of climatic extremes in a data poor transboundary river basin of India and Pakistan. International Journal of Climatology, 40(11), PP 4992-5010. https://doi.org/10.1002/joc.6501

4. Aslam, R. A., Shrestha, S., & Pandey, V.P. (2018). Groundwater vulnerability to climate change: A review of the assessment methodology. Science of The Total Environment, 612, 853-875. https://doi.org/10.1016/j.scitotenv.2017.08.237

5. Neupane, S., Shrestha, S., Ghimire, U., Mohanasundaram, S., & Ninsawat, S. (2021). Evaluation of the CORDEX regional climate models (RCMs) for simulating climate extremes in the Asian cities. Science of The Total Environment, 797, 149137. https://doi.org/10.1016/j.scitotenv.2021.149137

6. Ghimire, U., Shrestha, S., Neupane, S., Mohanasundaram, S., & Lorphensri, O. (2021). Climate and land-use change impacts on spatiotemporal variations in groundwater

recharge: A case study of the Bangkok Area, Thailand. Science of The Total Environment, 792, 148370. https://doi.org/10.1016/j.scitotenv.2021.148370

7. Background paper on "Framework for mapping groundwater resilience to climate change and human development in Asian cities".

6. Media reports, videos, and other digital content

1. Featured on Reuters on title "CORRECTED-FEATURE-As Nepal runs dry, communities tap water harvesting", published on October 6, 2021. https://www.reuters.com/article/nepal-climate-change-water-idUSL8N2PX2W9

2. Featured on Bangkok Post on title "City floods to worsen study", published on November 27, 2021. https://www.bangkokpost.com/thailand/general/2222475/city-floods-to-worsen-study

7. Pull quotes

"Higher temperatures will affect water demand and how groundwater is recharged by rain, which means the water shortage in Kathmandu Valley will get worse"

-Prof. Sangam Shrestha, AIT, Thailand

"One of the main lessons I have learned as project's partner is that broad partnerships are the key to solving broad challenges and creating a better project requires good teamwork, partnerships, and collaboration"

Dr. Bui Tran Vuong, DWRPIS, Vietnam

"I am very proud to be a part of this project. The lesson I learn from the project is, collaboration between government agencies, academia and local people is very important for sustainable management of groundwater resources"

Mr. Sanjiv Neupane, AIT, Thailand

"There is an urgent need to mitigate and adopt to climate change and tackle the issues of sustainable water security. Groundwater resources in major Asian cities is perceiving immense stresses due to population growth, rapid economic development along with climate change. It is very important to access the resiliency of groundwater to climate change and human development for strategic planning and management of water resources in urban areas"

-Dr. Monthip Sriratana Tabucanon, APN National Focal Point for Thailand and Senior Advisor, National Research Council of Thailand

8. Acknowledgments

We would like to express our sincere gratitude to the Asia-Pacific Network for Global Change Research (APN) for funding the project. We would also like to express our sincere thanks to Dr. Binaya Shivakoti from Institute for Global Environmental Strategies (IGES), Japan, Dr. Oranuj Lorphensri from Department of Groundwater Resources (DGR), Thailand, Dr. Bui Tran Vuong from Division of Water Resource Planning and Investigation for the South of Vietnam (DWRPIS), Vietnam, Dr. Muhammad Basharat from International Waterlogging and Salinity Research Institute (IWASRI), Pakistan, Dr. Rabin Malla from Center of Research for Environment Energy and Water (CREEW), Nepal and Dr. S. Mohana Sundaram from Asian Institute of Technology (AIT), Thailand. Our special thanks to several researchers, government officials, and non-governmental organizations who participated in this project directly and indirectly by providing valuable time, experiences and expertise, datasets, including being part of the workshops, and e-consultations conducted in this project.

9. Appendices

Appendix 1: First Regional Workshop on "Mapping groundwater resilience to climate change and human development in Asian cities", 5-7 August 2019

A three-day workshop on "Mapping groundwater resilience to climate change and human development in Asian cities" was successfully completed on 7 August 2019 at the Asian Institute of Technology (AIT), Thailand. The workshop was one of the activities of the project implemented by Asian Institute of Technology (AIT) and sponsored by Asia Pacific Network for Global Change Research (APN). The collaborators are Institute for Global Environmental Strategies (IGES), Japan, Department of Groundwater Resources (DGR), Thailand, Division of Water Resources Planning and Investigation for the South of Vietnam, Vietnam, International Waterlogging and Salinity Research Institute, Pakistan and Center of Research for Environment Energy and Water (CREEW), Nepal. The workshop focused on sharing groundwater environment of the four cities in the changing context and discussion on draft framework for mapping groundwater resilience to climate change and human development in Asian cities.

Delivering the opening remarks, Prof. Dieter Trau, Dean, School of Engineering and Technology, AIT highlighted the important role of groundwater in major cities of the world. He pointed out that the event is a capacity building opportunity as well as an avenue to jointly address the issues of climate change and water securities in cities. He also pointed out the problems on the groundwater resources and importance of the workshop to tackle those problems. Dr. Dieter thanked Asia-Pacific Network for Global Change Research (APN) for their support to the project. On behalf of APN, Dr. Monthip Sriratana Tabucanon, Scientific Planning Group of APN welcomed all participants and provided an overview of the activities of APN. Dr. Monthip ended her remarks underlining the importance of assessing the resiliency of groundwater to climate change and human development for strategic planning and management of water resources in urban areas. The workshop also included a keynote speech "Improving Groundwater Governance for Water Security" delivered by Prof. Mukund S. Babel, Professor, AIT, Thailand. In his speech he stressed the fact of uniqueness of groundwater, groundwater governance diagnostic analysis, and groundwater to be included in water security assessments.

The first day of the workshop witnessed a technical session consisting of presentations on climate change and land use change impact on groundwater resources. The areas covered modeling and non-modeling approach of assessing impact of climate change and land use change on groundwater resources. The second technical session witnessed the country delegates from Thailand, Vietnam, Nepal, and Pakistan delivering their presentation on groundwater environment in the project cities in the context of climate change and land use change.

The second day, which marked the conclusion of the workshop, saw an introductory presentation from Dr. Sangam Shrestha followed by methodological presentation from Mr. Sanjiv Neupane and Dr. S. Mohana Sundaram on the framework for mapping groundwater resilience to climate change and human development which acted as a starter for the following group discussion on finalizing the methodology of the framework. The group dialogue also includes discussion on the data requirement and availability in all Asian cities to carry out the methodology. After summarizing the discussion, Dr. Sangam Shrestha, PI of the project, thanked

all the participants and sponsors for making the event successful and expressed his hope that the outcome of the workshop would help the steady progress of the project as well as contribute towards strengthening future collaboration.

The third day of the workshop consisted of visit to Department of Groundwater Resources (DGR), Thailand, where the participants witnessed the presentations on groundwater situation of Thailand and Thailand Groundwater Monitoring System (TGMS). Followed by that field visit to groundwater and land subsidence monitoring wells at Chatuchak Park, Bangkok to learn about groundwater monitoring, land subsidence monitoring in Bangkok was done.

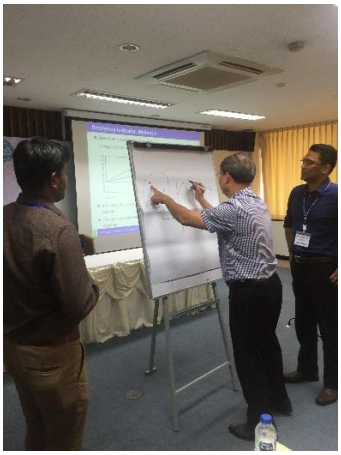
Some glimpse of the workshop

Dr. Sangam Shrestha, PI: Describing the project and objective of the workshop

Prof. Mukand S. Babel, Professor, AIT, Delivering Keynote Speech

Prof. Dieter Trau Dean, School of Engineering and Technology, AIT handing over token of appreciation to Dr. Monthip Sriratana Tabucanon, Scientific Planning Group of APN

Round table discussion on the framework for mapping groundwater resilience to climate change and human development in Asian Cities



Dr. Bui Tran Vuong, Deputy Director General, Division for Water Resources Planning and Investigation, Vietnam providing the constructive comments on the methodological framework

Dr. Sangam Shrestha, PI of the project handing over token of appreciation to Dr. Oranuj Lorphensri, Deputy Director General, Department of Groundwater Resources, Thailand

All the participants of the workshop posing for group photo during visit to Department of Groundwater Resource, Thailand

All the participants of the workshop posing for group photo in War Room of Department of Groundwater Resource, Thailand

Presentation on the groundwater and land subsidence monitoring well in Chatuchak park, Bangkok by DGR Representative

All the participants of the workshop posing for group photo during field visit for groundwater and land subsidence monitoring well in Chatuchak park, Bangkok

All the participants of the workshop: Posing for group photo

Appendix 2: Second Regional Workshop on Mapping Groundwater Resilience To Climate Change And Human Development In Asian Cities, 29 September 2021

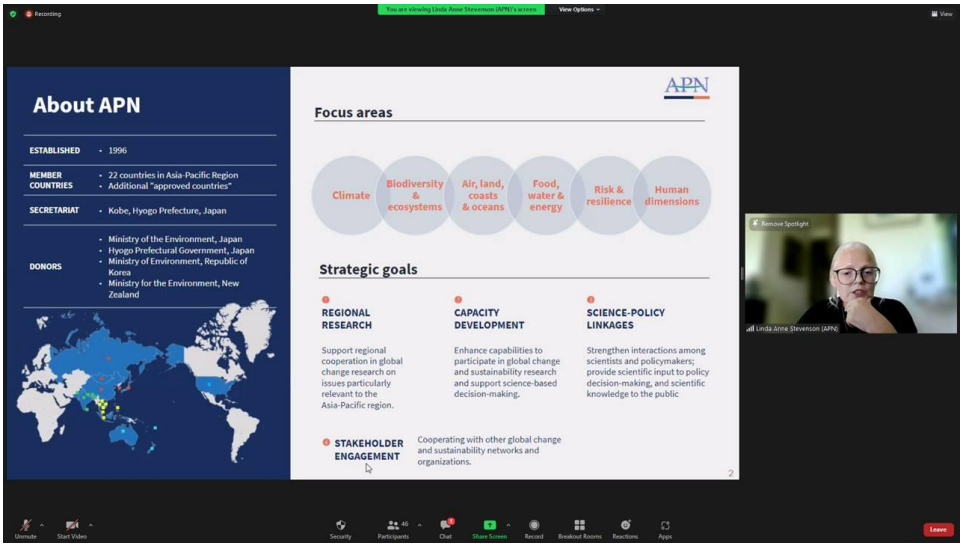
Asian Institute of Technology (AIT), Thailand together with Institute for Global Environmental Strategies (IGES), Japan; Department of Groundwater Resources (DGR), Thailand; Division of Water Resources Planning and Investigation for the South of Vietnam (DWRPIS), Vietnam; International Waterlogging and Salinity Research Institute, Pakistan (IWASRI) and Center of Research for Environment Energy and Water (CREEW), Nepal successfully organized the second regional workshop on "Mapping Groundwater Resilience to Climate Change and Human Development in Asian Cities" on Wednesday, 29 September 2021. The virtual workshop was the continuation of the first regional workshop conducted in August 2019 at AIT, Thailand. The project is funded by Asia-Pacific Network for Global Change Research (APN), an intergovernmental network that promotes policy-oriented research and capacity-building activities related to global change in the region.

Prof. Dieter Trau, Dean, School of Engineering and Technology, AIT delivered the opening remarks highlighting the thematic focuses of AIT in its education and research initiatives. Furthermore, he thanked project collaborators, APN, and emphasized the strategic importance of groundwater security in cities in the context of changing climate, population increment, industrial development, and alteration in land use. Prof. Dieter further expressed that the finding from the impact assessment on groundwater resiliency and the multiple adaptation strategies shall be useful to the researchers, policymakers, and managers of the region. Dr. Linda Anne Stevenson, Head of Knowledge Management & Scientific Affairs and Deputy Head of Development & Institutional Affairs, APN welcomed all the distinguished guests and participants of the workshop and provided an overview of APN, its activities in the Asia-Pacific region, and its contribution to global change research under multiple thematic areas. Furthermore, Dr. Stevenson stressed the urgent need to strengthen joint efforts for solution-oriented research, and interactions between the scientific community and policymakers for global safety and well-being in the context of various stresses.

Prof. Sangam Shrestha, Department Head, Department of Civil and Infrastructure Engineering (CIE), SET, AIT, and Principal Investigator of the project highlighted that the workshop objective is to create a platform for reviewing project progress and outputs, discuss the improvements needed for project methodologies and discuss the published and potential knowledge products. For this, the workshop consisted of three sessions namely Climate and land use change and population projection in Asian cities: Groundwater modelling and mapping resilience in Asian cities and Knowledge Products Development. Prof. Sangam Shrestha, Dr. S. Mohanasundaram, Mr. Sanjiv Neupane, and Ms. Usha Ghimire presented on several topics such as project introduction, its objectives, and methodologies, evaluation of several climates and land-use models, projection of multiple stresses, approaches used for hydrological, groundwater modelling, development of groundwater resiliency framework, its application and development of several knowledge products during the technical sessions.

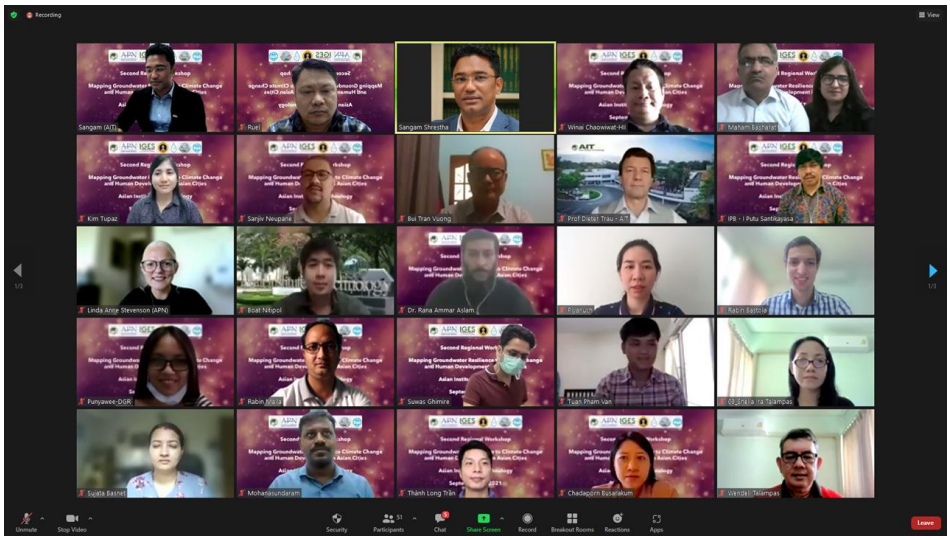
Prof. Sangam Shrestha in the closing sessions summarized the suggestions and comments received in each session and extended sincere thanks for their active participation in improving project methodologies and outputs. The intensive interactive workshop was attended by more than 45 participants representing different government institutes, universities, international organizations, and research organizations from India, Indonesia, Japan, Nepal, Pakistan, Thailand, and Vietnam.

Some glimpse of the workshop




Talking: Sangam Shrestha
Second R Workshop
Mapping Groundwat ce to Climate Change
and Hum sian Cities
Sangam (AIT)


Mapping Groundwater Resilience to Climate Change and Human Development in Asian Cities
Evaluation of RCMs and Climate Change Projection
Presented by:
Mr. Sanjiv Neupane (st121020)
PhD Candidate, Water Engineering and Management
Asian Institute of Technology, Thailand
29th September, 2021
Sanjiv Neupane


Sangam (AIT)
Sangam Shrestha
Kim Tupaz
Sanjiv Neupane
Bui Tran Vuong
Linda Anne Stevenson (APN)
Dr. Rana Ammar Aslam
Punyawee DSR
Rabin Bajra
Suwas Ghimire
Tuan Pham Van
Sujata Basnet
Mohanasundaram
Thành Long Trần
Unmute
Stop Video
Security
Participants
Chat
Share Screen
Record
Breakout Rooms
Reactions
Apps
Leave

Appendix 3: Project closure workshop on "Mapping groundwater resilience to climate change and human development in Asian cities", 20 December 2022

Asian Institute of Technology (AIT), Thailand together with Institute for Global Environmental Strategies (IGES), Japan; Department of Groundwater Resources (DGR), Thailand; Division of Water Resources Planning and Investigation for the South of Vietnam (DWRPIS), Vietnam; International Waterlogging and Salinity Research Institute, Pakistan (IWASRI) and Center of Research for Environment Energy and Water (CREEW), Nepal successfully organized the project closure workshop on "Mapping Groundwater Resilience to Climate Change and Human Development in Asian Cities" on Tuesday, 20 December 2022. The virtual workshop was the continuation of the first regional workshop conducted in August 2019 at AIT, Thailand and second regional workshop conducted virtually in September 2021. The project is funded by Asia-Pacific Network for Global Change Research (APN), an intergovernmental network that promotes policy-oriented research and capacity-building activities related to global change in the region.

Prof. Dieter Trau, Dean, School of Engineering and Technology, AIT delivered the opening remarks highlighting the thematic focuses of AIT in its education and research initiatives. Furthermore, he thanked project collaborators, APN, and emphasized the strategic importance of groundwater security in cities in the context of changing climate, population increment, industrial development, and alteration in land use. Prof. Dieter further expressed that the finding from the impact assessment on groundwater resiliency and the multiple adaptation strategies will be useful to the researchers, policymakers, and managers of the region. On behalf of APN, Dr. Monthip Sriratana Tabucanon, APN National Focal Point for Thailand and Senior Advisor, National Research Council of Thailand express her sincere appreciation to the AIT and project collaborators. Dr. Monthip added the urgent need to mitigate and adopt to climate change and tackle the issues of sustainable water security. She highlighted that groundwater resources in major Asian cities is perceiving immense stresses due to population growth, rapid economic development along with climate change. Dr. Monthip ended her remarks underlining the importance of assessing the resiliency of groundwater to climate change and human development for strategic planning and management of water resources in urban areas. Prof. Sangam Shrestha, Department Head, Department of Civil and Infrastructure Engineering (CIE), SET, AIT, Co-director, AIT Global Water Sanitation Center and Principal Investigator of the project highlighted that the workshop objective is to create a platform for reviewing project progress and outputs, discuss the improvements needed for project methodologies and discuss the published and potential knowledge products.

The workshop consisted of four sessions namely Climate and land use change and population projection in Asian cities: Mapping resilience of groundwater to climate change and human development in Asian cities: Panel discussion on sustainable groundwater management in Asian cities and Reflection from the project collaborators. First two sessions were the technical session where Prof. Sangam Shrestha, Mr. Sanjiv Neupane and Dr. S. Mohanasundaram presented on several topics such as project introduction, its objectives, and methodologies, climate change and land use change outlook in Asian cities and Resilience of groundwater to climate change and human development in Asian cities to disseminate the output of the project to experts, collaborators, and participants.

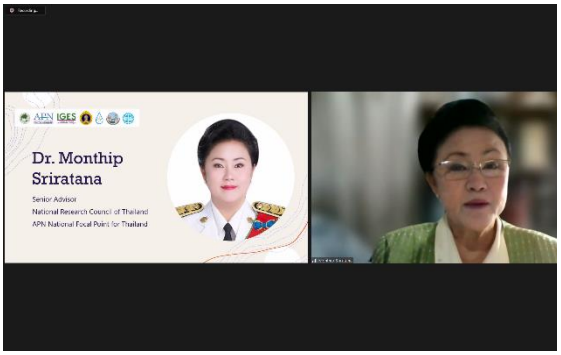
Third session which was panel discussion on sustainable management of groundwater resources was moderated by Prof. Sangam Shrestha. Four distinguish guests: Prof. Ashim Das Gupta, Professor Emeritus, AIT, Dr. Rana Ammar Aslam, Lecturer, University of Agriculture Faisalabad, Pakistan, Dr. Phayom Saraphiriom, Director, Groundwater Resources Institute (GWRI), Khon Kaen University, Thailand, and Dr. Jannet C Bencure, Dean, College of Engineering and Technology, Visayas State University, Philippines highlighted the strategies for sustainable groundwater management which includes: protection of groundwater recharge areas, controlling the landfill activities and industrial area management, controlling the abstraction up to safe yield, controlling of migration to the cities, development of structural measures like check dams and unlinking canals for increasing groundwater recharge, public awareness to reduce the groundwater uses and conjunctive use of surface and groundwater, use of Manage Aquifer Recharge techniques to improve recharge to the aquifers, improving groundwater governance and increasing collaboration with government, academia, and local people. Beside this all four distinguish panelist highlighted the importance of improving the quality of groundwater for sustainable management of groundwater.

The fourth and final session of reflection from project collaborators was chaired by Dr. Winai Chaowiwat where all the project collaborators share their reflection from the project. All four project collaborators highlighted that the project results can contribute to current debates about pathways of sustainable groundwater development and adaptation. Also, the results from the project can contribute to developing groundwater related policies in the Asian cities.

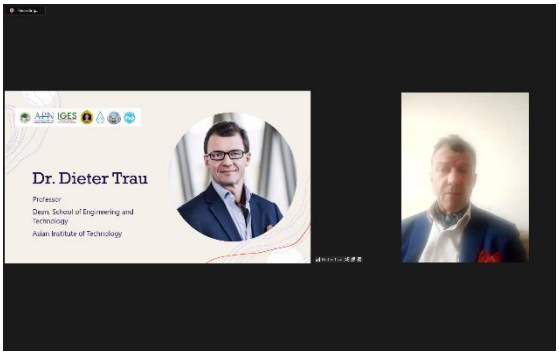
Dr. S. Mohanasundaram delivered the closing remarks by giving vote of thanks to Prof. Dieter Trau, Dr. Monthip Sriratana Tabucanon and Prof. Sangam Shrestha. He also expresses his gratitude to all the project collaborators, project team for their continuous support in the project. Lastly, he congratulates all the project team for the successful completion of the project.

Some glimpse of the workshop

Dr. Sangam Shrestha, PI: Describing the project and objective of the workshop

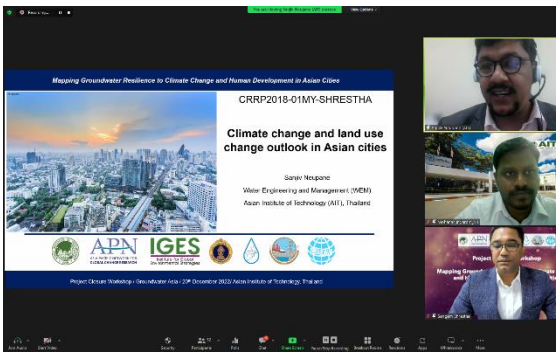


Dr. Monthip Sriratana delivering welcome remarks



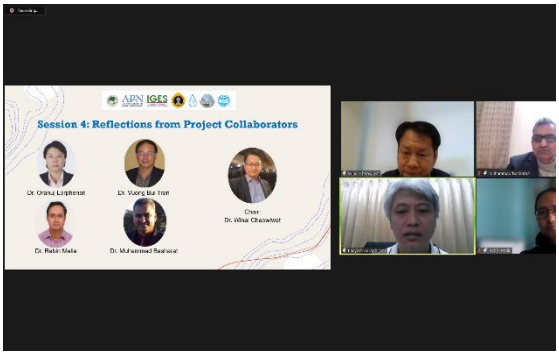
Prof. Dieter Trau Dean delivering opening remarks

Distinguish Panelist sharing their experiences on sustainable groundwater management

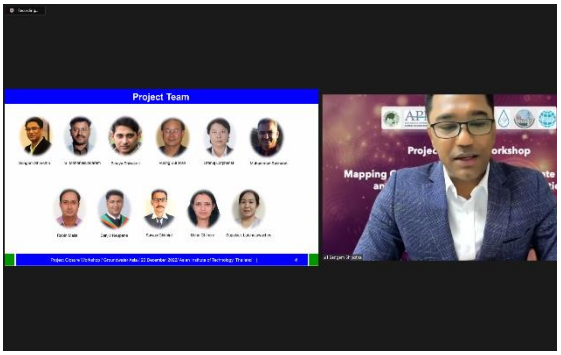


Mr. Sanjiv presenting on climate change and land use change outlook of Asian cities

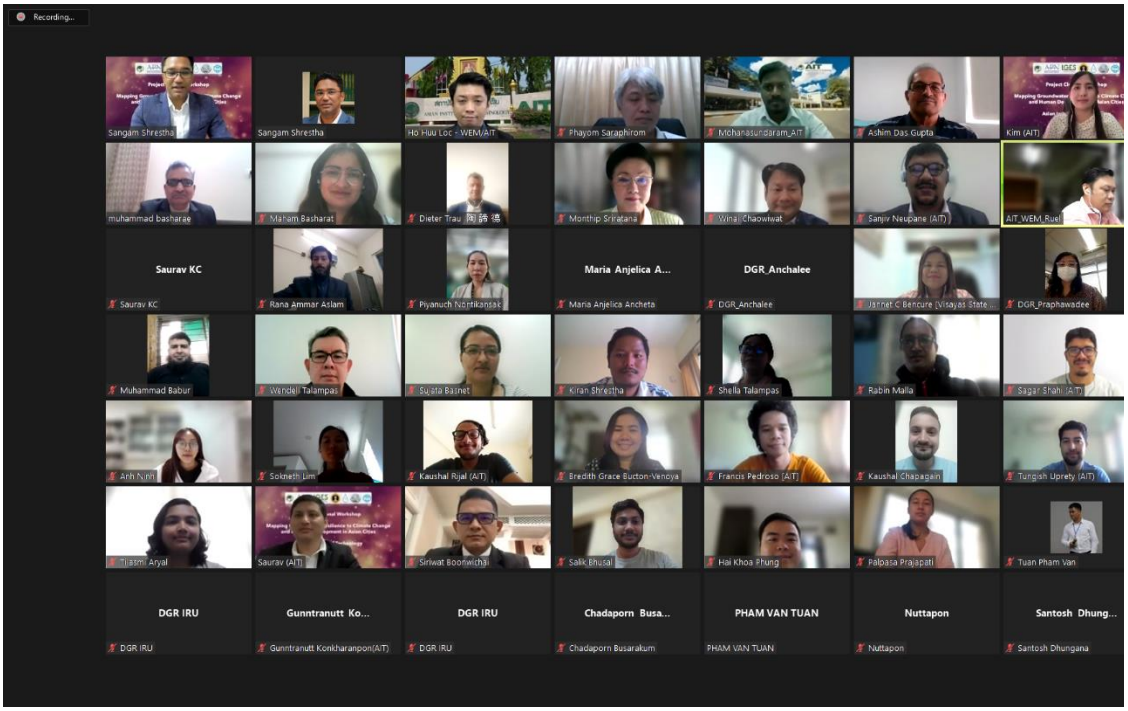
Dr. Mohana presenting on Resilience of groundwater to climate change and human development in Asian Cities



All the project collaborators providing their reflection on project



Prof. Sangam Shrestha introducing the project team to participants



All the participants of the workshop: Posing for group photo

Appendix 4: Journal Articles

1. Mapping groundwater resiliency under climate change scenarios: A case study of Kathmandu Valley, Nepal (Published in Elsevier, Environmental Research, IF 8.431)

Abstract

Groundwater resources of Kathmandu Valley in Nepal are under immense pressure from multiple stresses, including climate change. Due to over-extraction, groundwater resources are depleting, leading to social, environmental, and economic problems. Climate change might add additional pressure by altering groundwater recharge rates and availability of groundwater. Mapping groundwater resilience to climate change can aid in understanding the dynamics of groundwater systems, facilitating the development of strategies for sustainable groundwater management. Therefore, this study aims to analyse the impact of climate change on groundwater resources and mapping the groundwater resiliency of Kathmandu Valley under different climate change scenarios. The future climate projected using the climate data of RCM's namely ACCESS-CSIRO-CCAM, CNRM-CM5-CSIRO-CCAM and MPI-ESM-LR-CSIRO-CCAM for three future periods: near future (2010–2039), mid future (2040–2069) and far future (2070–2099) under RCP 4.5 and RCP 8.5 scenarios were bias corrected and fed into the Soil and Water Assessment Tool (SWAT), a hydrological model, to estimate future groundwater recharge. The results showed a decrease in groundwater recharge in future ranging from 3.3 to 50.7 mm/yr under RCP 4.5 and 19–102.1 mm/yr under RCP 8.5 scenario. The GMS-MODFLOW model was employed to estimate the future groundwater level of Kathmandu Valley. The model revealed that the groundwater level is expected to decrease in future. Based on the results, a groundwater resiliency map of Kathmandu Valley was developed. The results suggest that groundwater in the northern and southern area of the valley are highly resilient to climate change compared to the central area. The results will be very useful in the formulation and implementation of adaptation strategies to offset the negative impacts of climate change on the groundwater resources of Kathmandu Valley.

Keywords

Climate change, GMS-MODFLOW, Groundwater resiliency, Kathmandu valley, RCP

2. Climate and land-use change impacts on spatiotemporal variations in groundwater recharge: A case study of the Bangkok Area, Thailand (Published in Elsevier, Science of the Total Environment, IF 10.75)

Abstract

Groundwater contributes to the socioeconomic development of the Thai capital Bangkok and its vicinity. However, groundwater resources are under immense pressure due to population growth, rapid urbanisation, overexploitation, and climate change. Therefore, evaluating the combined impact of climate change and land-use change on groundwater recharge can be useful for developing sound groundwater management systems. In this research, the future climate is

projected using three Regional Climate Models (RCMs), namely ACCESS-CSIRO-CCAM, CNRM-CM5-CSIRO-CCAM, and MPI-ESM-LR-CSIRO-CCAM for three future periods: near future (2010–2039), mid future (2040–2069), and far future (2070–2099) under two Representative Concentration Pathway (RCP) scenarios 4.5 and 8.5 as suggested in the IPCC's Fifth Assessment Report. All RCMs project the temperature to rise incessantly, although future precipitation is predicted to fluctuate (increase and decrease) among the various RCMs and RCP scenarios. A Dyna-CLUE model is employed to analyse the future land-use change scenarios (low, medium, and high urbanisation), with the aim of expanding the built-up area and creating land-use maps covering the period to 2099. A hydrological model, WetSpass, is used to estimate groundwater recharge under future climate and land-use change. The findings reveal that groundwater recharge is expected to decrease in high and medium urbanisation areas, ranging from 5.84 to 20.91 mm/yr for the RCP 4.5 scenario and 4.07 to 18.72 mm/yr for RCP 8.5. In contrast, for the low urbanisation scenario, the model projects an increase in groundwater recharge ranging from 7.9 to 16.66 mm/yr for the RCP 4.5 scenario and 5.54 to 20.04 mm/yr for RCP 8.5.

Keywords

Climate change, Quantile mapping, Urbanisation, Dyna-CLUE, WetSpass, Bangkok

3. Evaluation of the CORDEX regional climate models (RCMs) for simulating climate extremes in the Asian cities (Published in Elsevier, Science of the Total Environment, IF 10.75)

Abstract

This study evaluates the ability of 21 Regional Climate Models (RCMs) from the Coordinated Regional Climate Downscaling Experiment (CORDEX) in simulating climate extremes in the fast-growing Asian cities which are highly vulnerable to climate change. The three Asian cities have two different climate characteristics, namely Bangkok and its vicinity and Ho Chi Minh City in tropical climate region and Kathmandu in sub-tropical and temperate climate region. The RCMs were evaluated to simulate the six climate indices; Consecutive Dry Days (CDD), Simple Daily Intensity Index (SDII), Number of extremely heavy precipitation days (R50mm), Maximum 1-day precipitation amount (RX1day), Mean of daily maximum temperature (TX mean) and Mean of daily minimum temperature (TN mean). The performance indicators used were correlation coefficient, normalized root mean square deviation, absolute normalized root mean square deviation and average absolute relative deviation. The Entropy method was endorsed to acquire weights of these four indicators and weightage average techniques were used for ranking of 21 RCMs. The result demonstrated that the best model for one climate index is not the same best model for other climate indices. The 3 RCMs; WAS44_SMHI_RCA4_IPSL_CM5A_MR, WAS44_SMHI_RCA4_MIROC5, and WAS44_IITM_REGCM4-4_CSIRO_MK3-6-0 are the best performing RCMs for simulating future climate extremes in Bangkok and its vicinity, Ho Chi Minh city and Kathmandu valley, respectively. Therefore, they are recommended to use for climate change impact and adaptation studies in water resources management in the selected cities.

Keywords

RCMs, CORDEX, Performance indicators, Climate indices, Entropy method, Asian cities

4. Impact of land-use change on groundwater recharge in the Ho Chi Minh City, Vietnam (Published in Elsevier, Environmental Research, IF 8.431)

Abstract

Ho Chi Minh City (HCMC), Vietnam has undergone tremendous transformation in land-use practices in the past few decades. The groundwater-related issues have also been a major concern in the fast-growing southern city of Vietnam. Quantitative prediction of the impact on groundwater recharge due to changes in the land-use pattern of a watershed is crucial in developing sound groundwater management schemes. This study aims to evaluate the impacts of change in land-use patterns on the quantity of groundwater recharge in HCMC. An empirical land-use projection model (Conversion of Land-use and its Effects, Dyna-CLUE) and a hydrological model (Soil and Water Assessment Tool, SWAT) was used for the study.

Three future land-use scenarios of Low Urbanization Scenario (LU), Medium Urbanization Scenario (MU) and High Urbanization Scenario (HU) were developed in Dyna-CLUE focusing on the increase of built-up area to generate land-use maps of HCMC until the year 2100. The land-use maps for all three scenarios were then used in the calibrated hydrological model SWAT to get the future recharge in the near future (2016–2045), mid future (2046–2075) and far future (2076–2100). The recharge was observed to increase in the far future of LU by 10% while reduction of 30% and 52% in annual average recharge was observed in far future of MU and HU respectively. It was, thus, observed that change in built-up area has a significant effect on the groundwater recharge in HCMC

Keywords

Groundwater recharge, Land-use, SWAT, Dyna-CLUE, Urbanization, HCMC

5. Projections of climatic extremes in a data poor transboundary river basin of India and Pakistan (Published in Wiley, International Journal of Climatology, IF 3.928)

Abstract

This study aims to project and characterize the climate extremes in Ravi River Basin (RRB) which is considered as a data poor transboundary basin located in India and Pakistan. Performance of the three GCDs against observation data was evaluated at three stations. A quantile mapping technique was used to correct the biases of four regional climate models (RCMs) and climate extremes were analysed for future period (2020–2095). Seven temperature and rainfall-based indices that represent warm and wet characteristics of climate were chosen. Four statistical parameters and spatial maps were evaluated for the base period 1982–2005. The CPC-NOAA and PU had the best performance for temperature and rainfall data regarding the time series analysis. The quantile mapping improved three important aspects of the climate cycle: the transitions from dry to wet and wet to dry seasons and peaks as well. At spatial scale, quantile mapping well captured the spatial distribution of the eleven indices other than RX1Day, CWD

and FD0. The results show that warm and wet extremes will increase in future at 5% significance level across the entire basin with large changes in northeast. The changes will be large for RCP8.5 scenario compared to RCP4.5 scenario and choice of the scenarios has dominant contribution in uncertainty than choice of the models

6. Groundwater vulnerability to climate change: A review of the assessment methodology (Published in Elsevier, Science of the Total Environment, IF 10.75)

Abstract

Impacts of climate change on water resources, especially groundwater, can no longer be hidden. These impacts are further exacerbated under the integrated influence of climate variability, climate change and anthropogenic activities. The degree of impact varies according to geographical location and other factors leading systems and regions towards different levels of vulnerability. In the recent past, several attempts have been made in various regions across the globe to quantify the impacts and consequences of climate and non-climate factors in terms of vulnerability to groundwater resources. Firstly, this paper provides a structured review of the available literature, aiming to critically analyse and highlight the limitations and knowledge gaps involved in vulnerability (of groundwater to climate change) assessment methodologies. The effects of indicator choice and the importance of including composite indicators are then emphasised. A new integrated approach for the assessment of groundwater vulnerability to climate change is proposed to successfully address those limitations. This review concludes that the choice of indicator has a significant role in defining the reliability of computed results. The effect of an individual indicator is also apparent but the consideration of a combination (variety) of indicators may give more realistic results. Therefore, in future, depending upon the local conditions and scale of the study, indicators from various groups should be chosen. Furthermore, there are various assumptions involved in previous methodologies, which limit their scope by introducing uncertainty in the calculated results. These limitations can be overcome by implementing the proposed approach.

Keywords

Adaptive capacity, Indicator, Exposure, Integrated approach, Sensitivity

Appendix 5: Thesis Articles

1. Assessment of groundwater vulnerability to climate change, land use change and abstraction scenarios in Lahore, Pakistan (PhD dissertation)

Abstract

Urban aquifers are facing increasing pressure from climate change, land use change and abstraction, altering groundwater levels and threatening sustainable water consumption availability and utilisation. Therefore, this study projects future changes of climate, land use and abstraction, while analysing the vulnerability of groundwater levels to such changes and formulating adaptation options to reduce the vulnerability of groundwater resources in Lahore. The objectives are achieved using modelling and qualitative approaches. The results show an increase in mean and extreme climate under climate change scenarios. The warm and wet extremes are projected to increase (significant at P=5%) under medium (RCP4.5) and high end (RCP8.5) scenarios. Annual changes in all climate indices will be significant except for the warm spell duration index. Land use projections show increased built-up in land use type from 965 to 3716 km2 and 3329 km2 under R1S1 and R2S2 scenarios (significant at P=5%). The built-up land use will dominate agriculture land use in the future. The future population will increase (significant at P=5%) from 6.4 M to 24.6, 27.5 and 28.7 M under SSP1, SSP2 and SSP3 scenarios, respectively. The vulnerability of urban areas will increase in the future due to the high negative impact and low adaptive capacity under combined scenarios. Agriculture and surrounding areas will remain less vulnerable in the future under combined scenarios due to the low negative impact and medium adaptive capacity. The results of this study may help groundwater experts and related institutions to understand the potential situation of groundwater resources in Lahore and formulate adaptation strategies to counteract diminishing groundwater resources in the area.

Keywords

Groundwater vulnerability, Climate change, Adaptive capacity, Land use change, Abstraction, Lahore.

2. Mapping Groundwater Resiliency under Climate Change Scenarios: A Case Study of Kathmandu Valley, Nepal (master thesis)

Abstract

Groundwater resources in Kathmandu valley, Nepal is perceiving immense stress due to high rate of abstraction along with climate change. The upshot of over abstracting groundwater results in declining groundwater levels and further leads to social, environmental, and economic problems. Climate change might add immense pressure on groundwater by affecting the groundwater recharge rates and change the availability of groundwater. Mapping groundwater resiliency can aid in understanding the dynamic of groundwater system thus, help in developing

the strategy for groundwater protection and management and sustainable use. This study emphasis on analysing the impact of climate change on groundwater resources and mapping the groundwater resiliency under different climate change scenarios.

The climate data forecasted by ACCESS, CNRM and MPI for three future periods; Near Future (2010-2039), Mid Future (2040-2069) and Far Future (2070-2099) and RCP 4.5 and RCP 8.5 scenarios were corrected using linear downscaling technique. All RCMs predicts that the temperature is continuously increasing in the study area, however, future precipitation is highly complex and uncertain and there was significant difference among various RCMs and both RCPs scenarios. A hydrological model SWAT developed basing on the meteorological data (1992-2005) along with DEM, soil map and land use map of the study area is used to estimate the groundwater recharge and suggest that groundwater will be decrease in future and the decrease in groundwater recharge ranges from 3.3 mm to 50.7 mm in RCP 4.5 scenario and 19mm to 100.8 mm in RCP 8.5 scenario. GMS-MODFLOW model was set up to estimate the groundwater level of Kathmandu Valley. Boundary conditions, recharge rates, pumping rates and hydraulic properties are the important input required to run the model. The model developed for 2001and 2008 using a three-layer conceptual model revealed that groundwater level will be decreased in future and decrease is up to 133.5m. Based on the result of GMS-MODFLOW, groundwater resiliency indicator is developed, and this indicator is used to generate the resiliency map of Kathmandu valley. It is found that groundwater will be highly resilient for the rural part of the valley and not resilient in the city area.

3. Mapping groundwater resilience to climate change and human development in Bangkok and its vicinity, Thailand (master thesis)

Abstract

Groundwater is the essential resource for various uses and have a great economic importance in Bangkok and its vicinity, Thailand. In this study area, groundwater is under immense pressure because of rapid urbanization, over exploitation of resources and climate change. Mapping groundwater resilience to climate change and human development can aid in understanding the dynamics of groundwater systems, facilitating the development of strategies for sustainable groundwater management.

The future climate projected using the climate data of RCM's namely ACCESS-CSIRO-CCAM, CNRM-CM5- CSIRO-CCAM and MPI-ESM-LR-CSIRO-CCAM for three future periods: near future (2010–2039), mid future (2040–2069) and far future (2070–2099) under RCP 4.5 and RCP 8.5 scenarios were bias corrected using quantile mapping technique. All RCMs predicts that the temperature is continuously increasing in the study area, however, future precipitation is highly complex and uncertain and there was significant difference among various RCMs and both RCPs scenarios. An empirical land-use projection model (Conversion of Land-use and its Effects, Dyna-CLUE) was used. Three future land-use scenarios of Low Urbanization Scenario (LU), Medium Urbanization Scenario (MU) and High Urbanization Scenario (HU) were developed in Dyna-CLUE focusing on the increase of built-up area to generate land-use maps of Bangkok until the year

2099. A hydrological model WetSpass developed is used to estimate the groundwater recharge and suggest that groundwater will be decrease in future for high and medium urbanization.

GMS-MODFLOW model was set up using boundary conditions, recharge rates, pumping rates and hydraulic properties. The average groundwater level is projected to increase in pumping scenarios S1 and S2, all land use scenarios and both RCPs scenarios. Whereas the average groundwater level is projected to decrease in pumping scenarios S3, all land use scenarios and both RCPs. Based on the result of GMS-MODFLOW, groundwater resiliency indicator is developed, and this indicator is used to generate the resiliency map of Bangkok and its vicinity. The area classified as “very highly resilient” is projected to increase for pumping scenarios S1 and S2 in future. Whereas, for pumping scenario S3, the area under “very high resilient class” decreases and area under “not resilient” class increases as we moved to future.

4. Mapping groundwater resilience to population and land use development scenarios: a case of Ho Chi Minh City, Vietnam (master thesis)

Abstract

Groundwater is very essential resource and a source of water in areas where the surface water sources are not adequate to meet the demand. But due to over abstraction and reduced recharge, sustainability of the groundwater is threatened. The groundwater in context of human development is studied in Ho chi Minh city, Vietnam in this research. Three future land use scenarios of low, medium, and high urbanization were developed focusing on the increase of built-up area. Projection of the land use was done using Dyna-CLUE model to develop land use maps. The land use map was then used in hydrological model SWAT to get the future recharge for all the scenarios after calibration. A groundwater model, GMS MOD-FLOW, was then setup and calibrated. Three different future pumping scenarios were developed. The estimated future recharge and the future pumping scenarios were then used to estimate the groundwater level. The groundwater levels are expected to decrease in all the land use and pumping scenarios. Based on the decrease water level compared to the baseline period, a resiliency indicator was developed, and mapping was done according to the indicator. Bottom aquifers are seen to be more resilient compared to the top four aquifer layers for the reduced recharge and increased abstraction

Appendix 6: List of young researchers

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Appendix 7: Conference Presentation

Topic	Authors	Conference/Symposium/Seminar Name	Year
Mapping Groundwater Resilience to Climate Change and Human Development in Bangkok and its vicinity, Thailand	Ms. Usha Ghimire	2nd AIT-BNU Joint International Virtual Workshop on Water, Health, and Ecosystems: Current Challenges and Opportunities jointly organized by Asian Institute of Technology (AIT), Thailand and Beijing Normal University (BNU)	2020
Evaluation of CORDEX Regional Climate Models (RCMs) for future climate extreme projection in Bangkok and its Vicinity, Thailand	Mr. Sanjiv Neupane	9th International Joint Student Seminar on "Civil Infrastructures" jointly organized by Regional Network Office for Urban Safety (RNUS), School of Engineering and Technology (SET), Asian Institute of Technology (AIT), Thailand and International Center for Urban Safety Engineering (ICUS), Institute of Industrial Science (IIS), University of Tokyo (UTokyo), Japan	2020
Evaluation of CORDEX Regional Climate Models (RCMs) for future climate extreme projection in Asian cities	Mr. Sanjiv Neupane	WEM seminar organized by Water Engineering and Management program, Asian Institute of Technology	2020
Mapping Groundwater Resilience to Climate Change and Human Development in Bangkok and its vicinity, Thailand	Mr. Sanjiv Neupane	THA 2022 International Conference on Moving Towards Sustainable Water and Climate Change Management After COVID-19	2022
Impact of climate change and land use change on spatiotemporal variation of groundwater recharge in Asian cities	Mr. Sanjiv Neupane	AGU Fall Meeting	2022