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Urban Water Management and Flood Risk Reduction – A platform to share integrated sustainable practices in Asian coastal countries

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1. Summary

Our project enhanced the application of GIS, remote sensing technique and developed the proper flood models coupling with river water quality model for urban flood management and water quality analysis in Asian coastal countries. We used the IoT tools to set up real time monitoring for developing early warning system and improve knowledge operationalizing such systems that can predict urban floods and reduce vulnerability using climate and non-climate information. In addition, we applied and downscaled the latest CMIP6 Socio-economic climate change scenarios (SSPs) in three study cities, and use the future change information in rainfall intensity to identify the climate change induced variation of the urban water cycle. Then, we assessed the flood risk, sediment and nutrient concentrations change under the latest CMIP6 future climate scenario to develop and implement Flood Risk Mitigation and Water Quality Improvement Plans. As outcomes, we identified on-site adaptation strategies that restore water cycle and reduce the range of variability in climate change induced flood and water scarcity in three coastal cities, respectively. Finally, we produced capacity development materials targeting local government officials and communities for implementing the research methodology.

In this project, we used different methods for Urban Water Management and Flood Risk Reduction, which is a platform to share integrated sustainable practices in Asian coastal countries. The main methodologies are described as follows:

- For three selected Asian coastal cities, set up the monitoring system and collect past and current hydrological and nutrient data to investigate and identify the current water cycle and hydrological processes. Downscale the latest CMIP6 climate change projection Socio-economic climate change scenarios (SSPs) to analyse the future climate change condition in the study cities.
- Establish a hydrological model combined with future climate projection to analyse the changes in the current water cycle and future water cycle change tendency, understand the differences in the current and future water change and distribution.
- Develop a river nutrient model that can be coupled to the hydrological model to comprehensively study how climate change and changes in river flow combined with human activities on land will impact surface water nutrient levels and flood water quality.
- Develop an urban wastewater model to simulate wastewater systems, including urban drainage, treatment plants and water flows. Assess how urbanization and changes in surface flow will impact the water environmental carrying capacity.
- Develop an integrated tool for water allocation and use, the management of water and nutrients. In implementing the model, the internal consistency will be ensured by using consistent sets of input data. The modelling framework will be used to assess improved water allocation and use in the three coastal cities, while accounting for water demand, water availability and water quality.
- Use the tool developed under this project to analyse scenarios for improved allocation of water in the coastal cities. Specifically, on-site measures will be identified, assessed and promoted, including traditional and new measures to reduce the projected variation range in the water cycles under both the worst and average projections of future climate scenarios.

- Research materials were synthesized into training modules for local government officials and communities as well as for postgraduate education and distance learning on climate change adaptation and urban safety.

2. Objectives

Overall objective of this project is to help improving urban water environment by developing policy tools, databases and modeling the effect of optimal land use and waste water treatment facilities that meets both socio-economic and ecological needs. The initiative has the following three focus areas:

- Water pollution mitigation
- Improvement of stormwater and sewerage management
- Ecosystem conservation

To achieve the above objectives, following policy assessments and tools were developed.

- Water quality index development
- Water pollution risk assessment
- Water quality modeling for alternative land use and wastewater treatment facilities
- Database development

3. Outputs, Outcomes and Impacts

Outputs	**Outcomes**	**Impacts**
Held the inception workshop	Finalize agreement on study sites, project and research strategy and 3-year plan, including a Policy Action Plan, Communications and Network Plan.	Enhance the capacities for researchers from the participating countries to engage in trans-disciplinary action-research related to this project.
Conducted social acceptability surveys and focus group discussions. The surveys provided the details of survey and questionnaire.	Determined the local government and community's promising stance on applying nature-based solutions for flooding disaster preservation and water treatment.	Raise awareness of local stakeholders of the potential of nature-based flooding disaster preservation and water treatment to contribute to addressing critical sustainability challenges.
Reviewed previously studies and suggested future needs of studies on water pollution in	Clear information of current knowledge and needs of studies	Improve achievement of water pollution measures

rivers		
Set up the monitoring system and completed real-time observation systems and data processing/archiving systems for IoT devices on GCP. Installed laboratory facilities for water quality analyses at the field sites.	More laboratory capacity to perform water quality research. Conducted 24 times of water quality sampling in the whole study basin, and carried out pollution investigation work.	Improve higher education and research quality.
Assessment of traditional measures in watershed water management, collection and survey of relevant parameters for hydrological and nutrient model. Developed methods for field water sampling, pretreatment, and analyses	More accurate and precise analyses of water quality in rivers	Improve the quality of life in individuals through research result
Set up a hydrological model with past, present and future climate data to analyze the hydrological processes and trends in water cycle . Develop a river nutrient model and couple with the hydrological model to analyze the changes in river flow and nutrient levels as well as flood water quality under the change of climate and human activities.	More knowledge in water quality sources for river water. Distinguished major sources of nitrate, phosphorus, COD, ammonium and other elements in river water. Iterative simulation of different on-site measures to restore the water cycle, identify the cost-effectiveness of on-site measures.	Reduction of water pollutants in rivers. Envisions an expansive horizon where the public can engage, contribute, and expand these simulated flooding and water quality maps by adding existing and new projects in other countries.
Downscale the latest CMIP6 climate change projection Socio-economic climate change scenarios (SSPs) to analyze the future flood risk and water cycle change. Record of the impacts of human activities on water quality.	Record of water quality, fertilization, crop production has been documented. Filtering algorithms to remove outliers and quality assurance. WRF model for 4-day weather forecasting was set up in GCP and automated. The algorithms for extracting forecasts matching with real time observation locations for automated bias correction is carried out.	Both of the water quality and quantity problems will be tackled by developing numerical models to simulate the current and future trend in different parts of this project.
Trained personnel in different	Traditional practices of farmers	This will increase jobs for the

project areas.	group during flooding period has been documented. Minimum of 15 trained manpower on using satellite remote sensing and water quality index has been produced.	farmers and local researchers. In addition, the freely available datasets are tried to be used to forecast the flooding and water quality.
One manual and brochures providing information on guides to the construction and installation of ecological ditches, oxidation pond, floating wetlands and water treatment systems. The manual also described the operation of constructed ecological ditches, oxidation pond, wetlands as well as selecting plants. The manual have been published in He et al. (2023).	The published methodology and guide have a positive and wide-ranging impact on flooding disaster preservation, water treatment, public health, environmental conservation, and sustainable development. It provides valuable tools and knowledge to promote the effective use of eco-friendly water treatment technologies.	The guide may influence policy and regulatory decisions related to flooding disaster preservation, water treatment technologies. It can provide local governments and watershed management organizations with the information and guidelines needed to develop or refine policies supporting flooding disaster preservation and water treatment methods.
A manuscript providing the details of the project has been submitted to APN Science Bulletin for peer review and publication	Submitting a manuscript to the APN Science Bulletin for peer review and potential publication is a significant step in academic and scientific recognition.	When published, it can enhance the visibility and credibility of the project, encouraging further research and collaboration in this field.
An IoT platform has been deployed on Google Cloud Platform (GCP) that retrieves real time data (20- 30 sec interval) continuously, archive the data in an online accessible database and provide graphical visualization of real-time information and warnings.	• Detailed instructions provided on line for users to set up a real time weather station and connect to cloud system. • Graphical display of environmental variables made available through the online system. • Three stations deployed at 3 Universities receiving daily summaries of environmental variables through reports emailed.	• Institutional capacities to install and use real time weather stations developed. • Data made available for graduate research of participating Universities. • Viability of low-cost system for monitoring and processing high resolution weather information demonstrated.
Developed a system for real time data retrieval, cleaning and archiving environmental	• A readily available easy to access environmental monitoring system has	• The disaster management communities have been empowered to receive

variables such as rainfall, temperature, etc., and water level from 50 weather stations and over 45 water levels measuring devices for Kelani River basin of Sri Lanka. The system also can be used as early warning system and to identify risk prone areas using the spatial information deployed by the system	been developed. • An early warning providing time as well as special distribution of rain and water-levels of water ways in the Kelani River basin has been deployed that serves as an early warning system and identification of risk prone areas.	and act on environmental information related to urban flooding in Colombo basin. • Valuable lessons from historical data have been used in the analysis of hydrometeorological disasters in selected study basin.
• The SWMM model, a popular urban storm water drainage model is deployed on line with an easy to use user interface that allows setting up and running the model on line. • Two videos were developed highlighting (a) the impact of urbanization on the increase of urban runoff and (b) the effect of nature-based solutions in reducing direct storm water runoff reduction and improving environmental functions. • A modeling system for simulating infiltration systems in urban areas is deployed on-line that couple the runoff model with an infiltration – storage model. A demonstration of a real-world case study deployed as a digital twin allows the user to try out various configurations of runoff reduction systems to assess the effectiveness of nature-based solutions in managing urban	• An accurate understanding of the storm runoff for different land use conditions and different types of rainfall patterns and intensities (figure 6). • Increasing public as well as student awareness on impact of urbanization on urban storm water runoff increment. • Urban storm water runoff reduction using nature-based systems, i.e. infiltration systems, and the ability to design optimum systems by testing different configurations using a digital twin.	• Accurate early warning using urban storm water runoff model. • Reduction of urban storm water runoff by deploying infiltration systems

environment.		
• A course module developed that can be delivered through zoom • A system for student enrolment, assessment and grading and discussion platform developed	• Couse conducted with students from China and professors from Sri Lanka and Japan • Twelve postgraduate students from three different Chinese Universities received training on first deployment of SWMM training course.	• An effective and efficient course to enhance the knowledge and analytical skills of graduate students to model urban storm runoff developed. • A tool for applied real world • Problem solving through peer discussion and contribution from remotely located participants developed.

4. Key facts/figures

(1) 5 monitoring system/online system/experiment base/platform/database were built:

- 1 IoT Real time monitoring system was built
- 1 On line system for continuous monitoring, analysis and visualization of urban water environment was developed
- 1 experiment base was constructed in Guangzhou, China; laboratory basic equipment and analytical instruments were installed
- 1 Platform and 1 database were updated in the project webpage

(2) 22 publications:

- 17 Journal articles
- 3 Books
- 2 Reports (including this final report)

(3) 30 Events held (workshops, training events, conferences, etc)

- 6 times' field training in China, 50 early-career professionals trained
- 2 time training via Virtual Meeting
- 5 Field Trips by the APN team
- 3 field monitoring system installed by APN team members
- 12 Focus group discussions
- 2 Socio-economic surveys
- 4 conferences and symposiums:

a) Held the special session “Exploring farm pond dynamics in low-order agricultural watersheds: A synthetic analysis and process-based modeling” in EGU General Assembly.

b) Members of our research group were invited to participate in the 2nd Water dialogue on 27th April, 2022. It was a virtual workshop on “Sustainable Water Governance in Central Asia Aimed Climate Vulnerabilities", which was jointly held by the Central Asia Regional Economic Cooperation (CAREC) Institute, the Asian Development Bank (ADB), ADB-PRC Regional Knowledge Sharing Initiative (RKSI).

c) Project team group jointly hold The 2nd International Symposium on "Water-Energy-Food" Nexus and a sub-venue session of the 2022 Youth Geoscience Forum of China. The platform and outcome of our project was introduced in this symposium.

d) Project team group hold The 3rd International Symposium on “Water Resources Management and Comprehensive Reclamation of River Basins” in 16-19 Dec. 2022. The platform and outcome of our project was introduced in this symposium.

(4) Monthly flooding, water environment disasters, flooding maps have been produced

- One manual for using the flooding and water quality index for calculating water disasters has been developed
- One awareness booklet on water quality and floodings been developed

(5) 5 Awards/Honors:

- Prof. He Bin has been elected as the Chair of “Committee on Environment and Disaster in Waterfront Area” in ICGdR (International Consortium on Geo-disaster Reduction). The outcomes of our APN project will be introduced and put into dissemination through the committee activities.
- Prof. He Bin has been elected as the Vice Chair of “Committee on Remote Sensing” in CNC-IAHS (Chinese National Commission for the International Association of Hydrological Sciences).
- Prof. He Bin’s research result “High stable tubular membrane technology for agricultural wastewater treatment” was awarded as the Silver Medal in the 48 international inventions exhibition in Geneva, 2023.
- Prof. He Bin’s research result “Integrated Space-aerial-ground Comprehensive Monitoring and Distributed Modeling Technology for Hydro-environmental Disaster Reduction” was awarded as the First Prize by ICGdR Technology Invention Award, 2023.
- Prof. He Bin was awarded as “JSWE-IDEA International Exchange Award” by Japanese Society of Water Environment in March 2024.

5. Publications

Books:

1) He, B., Zhang, S.Y., Sun, Y., Zhou, K.J., Huang, W.Q. (2024). Agricultural non-point source pollution control - Ecological agriculture technology model and manual. Science Press.
2) Chen W., He, B., (2022). Hydro-environmental assessment of small water bodies: From local to global scales. Chongqing University Press.
3) Duan, W., Maskey, S., Chaffe, P., Luo, P., He, B., Wu, Y., Hou, J. (Editors). （2021） Remote Sensing in Hydrology and Water Resources Management, MDPI Publisher.

SCI Journals:

4) Liu, L., Wu, R., Lou, Y., Luo, P., Sun, Y., He, B., Hu, M. and Herath, S., 2023. Exploring the Comprehensive Evaluation of Sustainable Development in Rural Tourism: A Perspective and Method Based on the AVC Theory. Land, 12(7), p.1473.
5) Zhu, W., Zha, X., Luo, P., Wang, S., Cao, Z., Lyu, J., Zhou, M., He, B., Nover, D. (2023). A quantitative analysis of research trends in flood hazard assessment. Stochastic Environmental Research and Risk Assessment. 2023 Jan;37(1):413-28.
6) Zhu, W., Cao, Z., Luo, P., Tang, Z., Zhang, Y., Hu, M., He, B. (2022). Urban Flood-Related Remote Sensing: Research Trends, Gaps and Opportunities. Remote Sensing. 2022 Nov 1;14(21):5505.
7) Zhang, S.Y., Zhang, Z.H., He, B., Jiang, Z.Y., Li, X.Y. (2023). Interactions between shrub encroachment and water infiltration on the hillslope of a typical steppe. Ecohydrology. 2023 Jan;16(1):e2489.
8) Luo, P., Zheng, Y., Wang, Y., Zhang, S., Yu, W., Zhu, X., Huo, A., Wang, Z., He. B., Nover, D. (2022). Comparative assessment of sponge city constructing in public awareness, China. Sustainability. 2022 Sep 16;14(18):11653.
9) Cao, Z., Zhu, W., Luo, P., Wang, S., Tang, Z., Zhang, Y., Guo, B. (2022). Spatially non-stationary relationships between changing environment and water yield services in watersheds of China’s climate transition zones. Remote Sensing. 2022 Oct 11;14(20):5078.
10) Hao, B., Wu, H., You, Y., Liang, Y., Huang, L., Sun, Y., Zhang, S., He, B. (2023) Bacterial community are more susceptible to nanoplastics than algae community in aquatic ecosystems dominated by submerged macrophytes. Water Research. 2023 Apr 1;232:119717.
11) Hao, B., Wu, H., Zhang, S., He, B. (2022). Individual and combined toxicity of microplastics and diuron differs between freshwater and marine diatoms. Science of The Total Environment. 2022 Dec 20;853:158334.
12) Hao, B., Wu, H., Zhang, S. and He, B., 2024. Response strategies of stem/leaves endophyte communities to nano-plastics regulate growth performance of submerged macrophytes. Journal of Hazardous Materials, 464, p.132883.
13) Ma, Y., Gao, F., Pan, R., Jiang, Z., Li, D., Zhao, X., Wang, Y., He, B. (2022). Separation membranes with long-term stability and high flux prepared through intramembrane dopamine-based nanoparticle assembly. Journal of Membrane Science. 2022 Jul 15;654:120563.

14) Ma, Y., Gao, F., Pan, R., Jiang, Z., Zhao, X., Wang, Y., He, B. (2023). Long-Term Stability and High Flux Membrane Prepared Through Intramembrane Dopamine-Based Nanoparticle Assembly. Available at SSRN 4049429.
15) Liu, Y., Ji, C., Wang, Y., Zhang, Y., Jiang, Z., Ma, Q. and Hou, X., 2023. Effect of the quality of streamflow forecasts on the operation of cascade hydropower stations using stochastic optimization models. Energy, 273, p.127298.
16) Liu, Y., Ji, C., Wang, Y., Zhang, Y., Hou, X. and **e, Y., 2022. Quantifying streamflow predictive uncertainty for the optimization of short-term cascade hydropower stations operations. Journal of Hydrology, 605, p.127376.
17) Liu, L., Chen, M., Luo, P., Duan, W. and Hu, M., 2023. Quantitative Model Construction for Sustainable Security Patterns in Social–Ecological Links Using Remote Sensing and Machine Learning. Remote Sensing, 15(15), p.3837.

Papers published in Chinese:
18) Chen, W., Li, H., He, B., Tao, L. Influence of Co-existing Anions and Cations on Phosphate Sequestration onto Goethite. Ecology and Environmental Sciences, 2022, 31(1): 151-159.
19) He, B., Hu, M. Evaluation of Agriculture Non-point Pollution Load and Its Characteristics in All Districts and Counties of Guangdong. Ecology and Environmental Sciences, 2022, 31(4): 1-6.
20) Han, Z., Wang, Y., He, B. Multi-component Runoff Simulation in Arid Area Based on BP Neural Network. Pear River, 2021, 42(4): 84-89.

6. Media reports, videos and other digital content

Project introduction webpage.
https://www.enviforecasting.com/apn

Deploying a local weather station
http://www.enviforecasting.com/node/36

IOT device set up
http://35.224.116.55/

Real time monitoring
http://35.224.116.55/

Urban runoff reduction
https://urban.enviforecasting.tech/

Digital Twin
http://34.122.96.234/

SWMM training
http://www.enviforecasting.com/node/16

Featured on Chinese Science Post on title “Using new type membrane to treat water pollution”, published on April 22, 2022.
https://news.sciencenet.cn/htmlpaper/2022/4/20224221652357972243.shtm

Featured on Science 1633 Post on title “Prof. He was awarded by International Consortium on Geo-disaster Reduction”, published on Jan. 24, 2023.
https://www.1633.com/article_univ/253660.html

7. Pull quotes

“One of the most remarkable projects I've had the privilege to be part of, collaborating with an exceptionally cordial team from the China, Sri Lanka, Thailand, and Japan. We achieved outstanding results and significant impacts during COVID with limited resources.”

- Prof. Herath Srikantha, Center for Urban Water, Sri Lanka

“ I feel privileged to be part of this APN project. It has provided me with essential knowledge in nature-based wastewater treatment and flooding disaster research. The project also allowed me to engage with experts, participate in seminars, and exchange valuable insights. ”

- Prof. Bam Razafindrabe, University of the Ryukyus, Japan

“I am very much thankful to APN for Global Change Research for funding the project and the APN staff for their great support to the project. I'm grateful to the APN Project for helping me complete my Master's thesis.

- Ms. Qian Xiao, North China Electric Power University, Beijing, China

“I did my master's thesis work on this project. I learned many things about water pollution issues. The project gave me an excellent opportunity to make my master's thesis successfully.”

- Mr. Ken Xu, South China Normal University, Guangzhou, China

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 like to thank all our collaborators for their support and kind understanding while doing this research work also in the COVID time, including all the team of this project work, the research assistant, program manager, field data collectors, technical supervisors and the advisor 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. Our special thanks to APN staff Dr. Linda Anne Stevenson, Dr. Nafesa Ismail, Ms. Aiko Seki and Ms. Naomi Young for their great support and timely responses to our requests.

9. Appendices

Appendix 1. Hydrometeorological data archiving and dissemination platform development

The services provided by EnviForecasting platform that are utilized for the APN dissemination is briefly described below.

1．Cloud System

The system is developed in Google cloud which provide the following services.

- IAS – infrastructure as a service; which allows the users to deploy dedicated server machines to carry out database, analysis and simulation tasks
- PAS – platform as a service; which allows deployment of computing functions or webservices utilizing the cloud platform's built in services without deploying servers in the system

At first the services provided by EnviForecasting utilizing both IAS and PAS will be used in the present project. Later it may be possible to develop and deploy dedicated services related to the current project.

2. Data Collection and sharing platform

The current project utilizes IoT (Internet of Things) devices for the collection of data. In the first-year weather data collection through IoT devices was completed. The selected system facilitates IoT data collection through two different mechanisms.

- Connection of IoT devices to Google IOT Core and make data available through Pub/Sub scheme of the system. This will make it possible to connect devices either through the http protocol or MQTT protocol, which will be converted to usable data by the cloud system.
- Data retrieval carried out though a 3rd party solution provider and either used directly from the provider or by re-directing to EnviForecasting IoT platform's Nginx /Flask server combination

After investigating the above two mechanisms, it was decided to utilize the IoT server platform developed by Envi forecasting LLC due to its efficiency and low operational cost. The IoT platform used consist of a NGINX web server and Flask Python framework to interact with incoming requests and serving products as per requests. Since the framework can be utilized for direct interaction with Python programming, it is easy to develop and deploy new applications. This configuration also makes it possible to utilize new and emerging application frameworks to be incorporated in to the platform being developed. With this upgrade, monitoring devices are able to directly communicate with the application programs developed by the users.

The IoT devices deployed under the present program directly communicate with the IoT platform, and data input and archiving are carried out with tags specific to different projects and users. Three main databases are dedicated to the project: observations, forecast simulation, and impact analysis.

3. Rapid Analysis interface

Recent developments in real-time data assimilation and analysis, especially in the development of autonomous vehicle driving systems, have made it possible to carry out online, real-time research analysis without much delay. Such a framework is employed to facilitate online research collaboration when sharing practices in different countries.

The improved interface of the system is shown in figures 1.1 to 1.4.

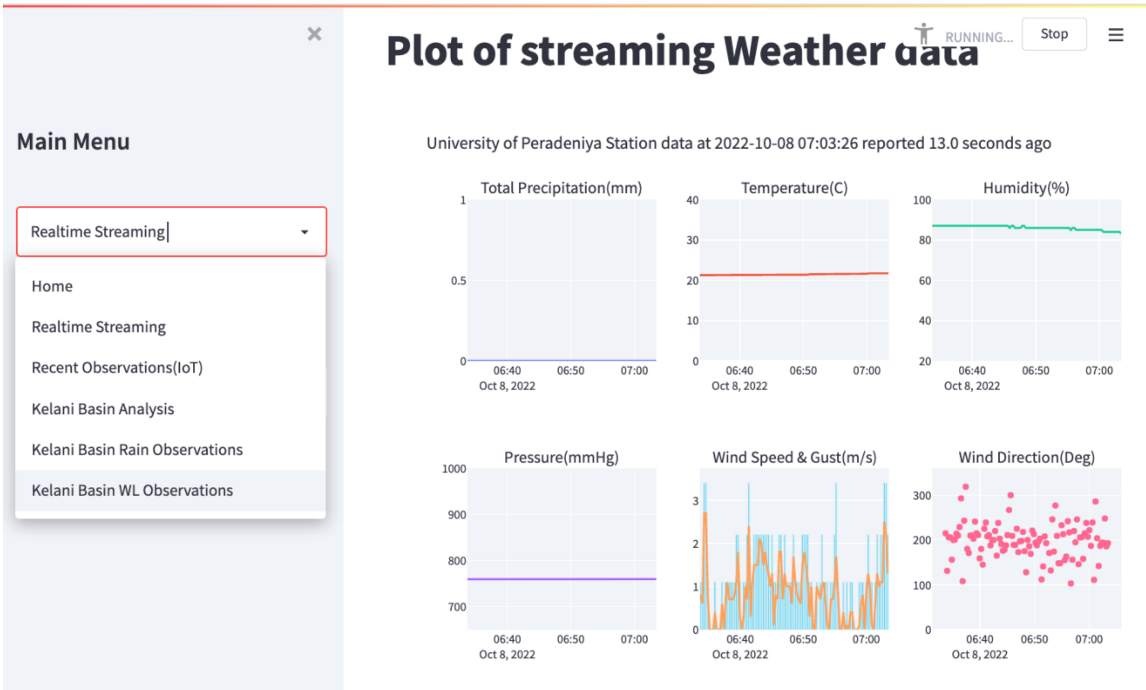


Fig 1.1 Drop down interface and dissemination of streaming data in real time of the reported parameters. Automatically updated every 15-20 seconds seamlessly.

Any of the dropdown menus lead to generation of required pages dynamical in real time. They can be sorted, searched and displayed in either graphical format or table format as required.

The display of a rainfall data in various available formats are displayed from figures 6.2, 6.3 and 6.4,

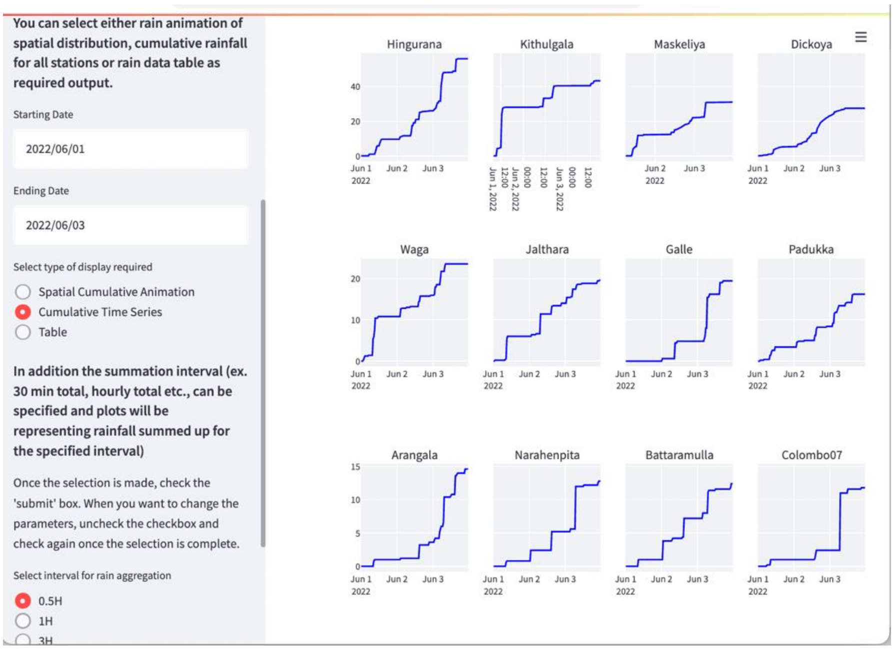


Figure 1.2 Display of cumulative rainfall from 2022-06-1 to 2022-06-03 from all available sensors. The data can be summarized in 0.5 hrs to 1 day intervals quickly in real time using the menu options.

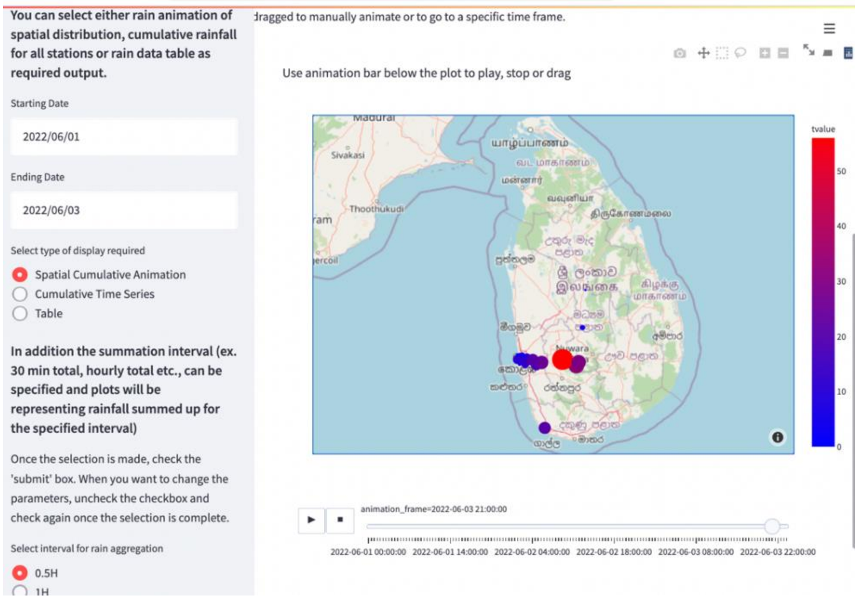
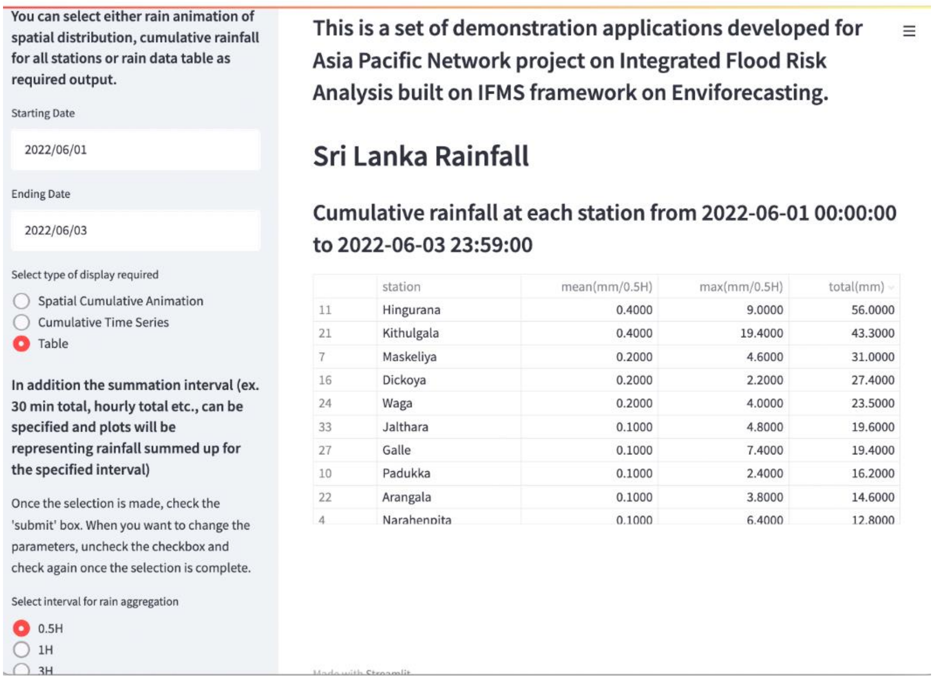


Figure 1.3. The total rainfall shown as a spatially distributed animation accumulated in selected time interval over the selected period. The color and size indicate the total rainfall at a given time.



	station	mean(mm/0.5H)	max(mm/0.5H)	total(mm)
11	Hingurana	0.4000	9.0000	56.0000
21	Kithulgala	0.4000	19.4000	43.3000
7	Maskeliya	0.2000	4.6000	31.0000
16	Dickoya	0.2000	2.2000	27.4000
24	Waga	0.2000	4.0000	23.5000
33	Jalthara	0.1000	4.8000	19.6000
27	Galle	0.1000	7.4000	19.4000
10	Padukka	0.1000	2.4000	16.2000
22	Arangala	0.1000	3.8000	14.6000
4	Narahenpita	0.1000	6.4000	12.8000

Fig. 1.4 Indicate the same data as a table which can be sorted in real time

Appendix 2 IoT Server and weather data collection

Several available weather stations have been reviewed and tested for ease of deployment, low cost and reliable data procurement. Then the process for acquiring and deploying weather station has been generalized so that any partner organization make use of the IoT platform to deploy and utilize the system for data collection and dissemination. The description of how to install and configure a weather station is outlined as document in the web platform as shown in Figure 2.1.

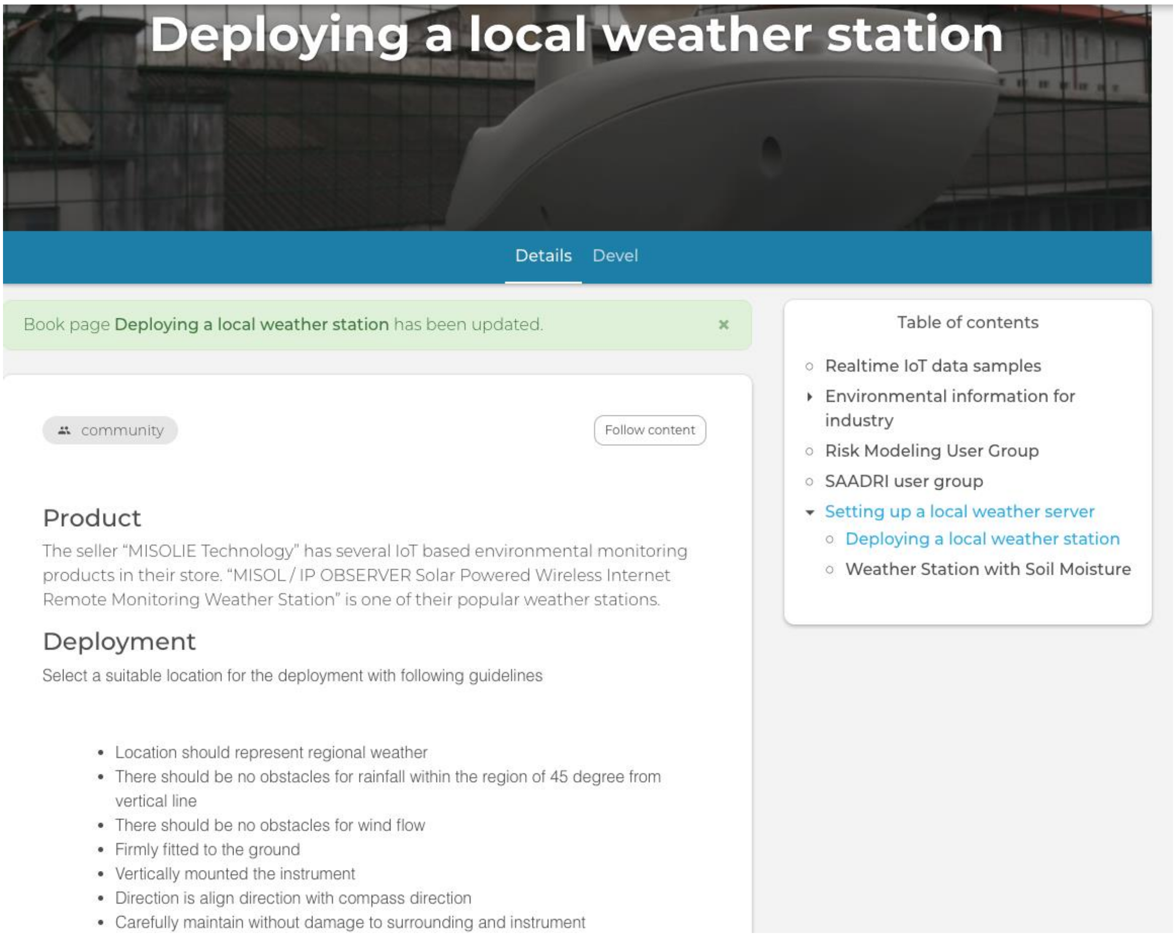


Figure 2.1 The description of how to install and configure a weather station

2.1 Setting up a local weather station

MiSOILiE weather stations were selected for the project and the documentation for the deployment and configuration of the weather station is provided in the web platform as follows.

2.1.1 Deployment

Select a suitable location for the deployment with following guidelines

- Location should represent regional weather
- There should be no obstacles for rainfall within the region of 45 degree from vertical line
- There should be no obstacles for wind flow
- Firmly fitted to the ground
- Vertically mounted the instrument
- Direction is align direction with compass direction
- Carefully maintain without damage to surrounding and instrument

2.1.2 Assembling the station

a. Power-up the receiver

There are two ports at the back of router; one for power and the other to connect to network.

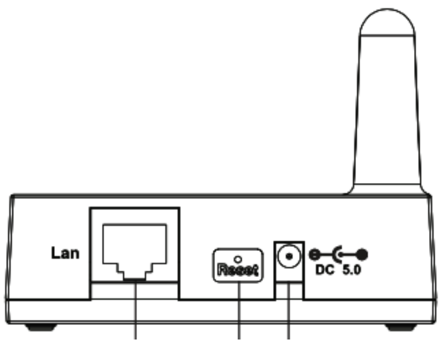


Figure 2.2 Power supply unit

Power supply unit consisting with power code, jack to connect to router and transformed unit to 230v to 5v.

b. Connect receiver to router with ethernet cable

Ethernet cable used to transfer data received in RF medium to server given network connectivity.

c. Install batteries in the outdoor sensor and indoor sensor

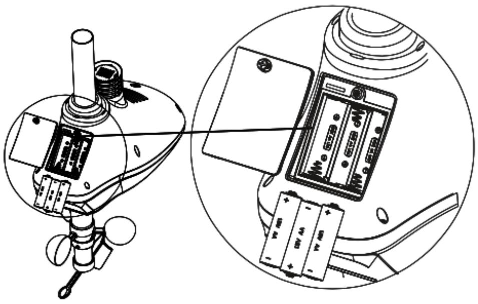


Figure 2.3 Outdoor sensor and indoor sensor

For outdoor sensor used three unit of AA Batteries while indoor unit is two unit of AAA batteries.

Batteries last for years for 24x365 usage.

Figure 2.4 Batteries installing

Make sure the outdoor and indoor sensors are reporting to the receiver.

To make sure that data is receiving to router can be shown by light indicating in indoor unit of router, similarly indoor unit also have a blinking light in a router. Light is on indicate those unit are connected, and data is received.

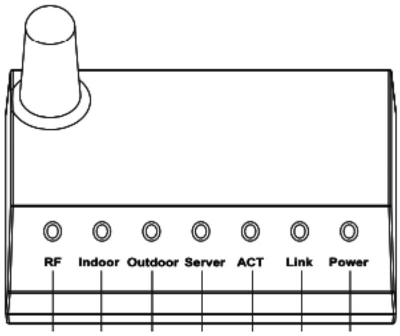


Figure 2.5 Router shown by light indicating in indoor unit of router

2.1.3 Installation on site

a. Choose the receiver location and outdoor sensor location within the range of each other

Indore and outdoor unit transmit data in form of RF communication medium. This medium provide 30m range and above restriction to receiver and transmitter it change by maximum distance.

Table 2.1 Indore and outdoor unit transmit data

Medium	RF Signal Strength Reduction
Glass (untreated)	5-15%
Plastics	10-15%
Wood	10-40%
Brick	10-40%
Concrete	40-80%
Metal	90-100%

b. Place the mounting pole for outdoor sensor steadily and vertically

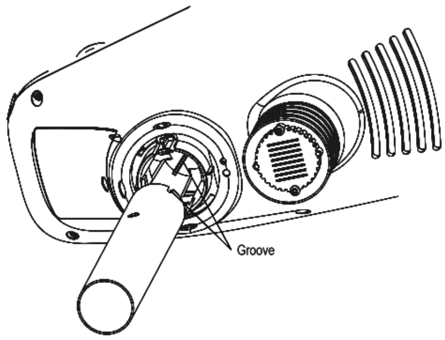


Figure 2.6 Place the mounting pole for outdoor sensor steadily and vertically

There is rod that connected to mounting purposes for outdoor unit to stay vertical. Unit fixed this rod by connecting mechanism show in above diagram.

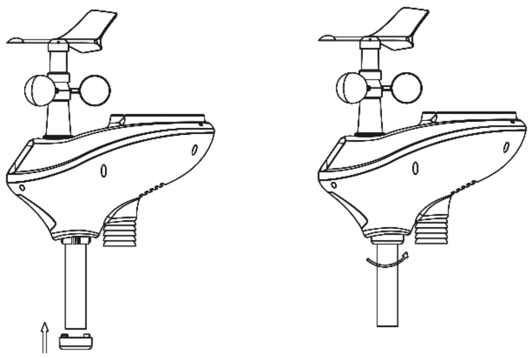


Figure 2.7 Mount the outdoor sensor to mounting pole

c. Mount the outdoor sensor to mounting pole

Include package with 3ft steel bar to connect outdoor unit and bracket to steel bar connect with pole that support vertical up the outdoor unit

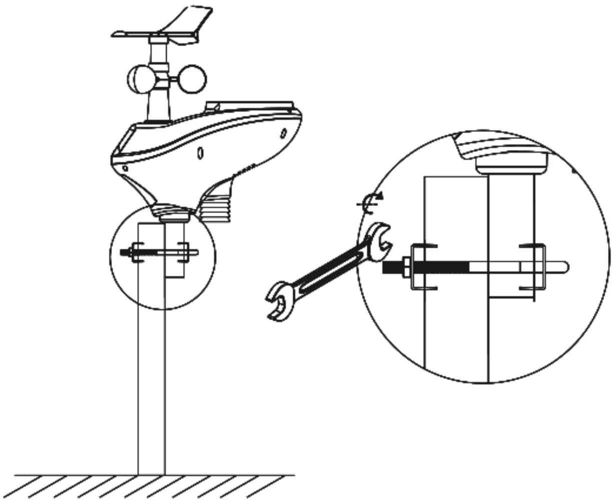


Figure 2.8 Check the level of outdoor sensor

d. Check the level of outdoor sensor

Use of water bubble placed in outdoor unit keep check vertical adjustments.

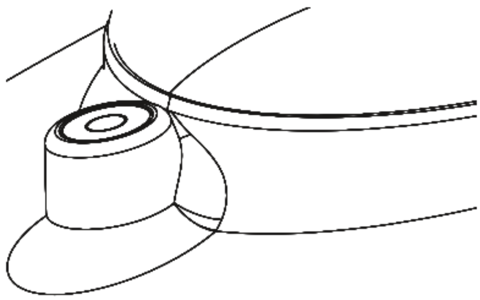


Figure 2.9 Water bubble placed in outdoor

2.1.4 Configure station

It is necessary to find the ip address of the station in the local area network to which the it is connected. This can be done with a tool such as IP tools. Then access the station directly with the identified ip address to see a window similar to the following.

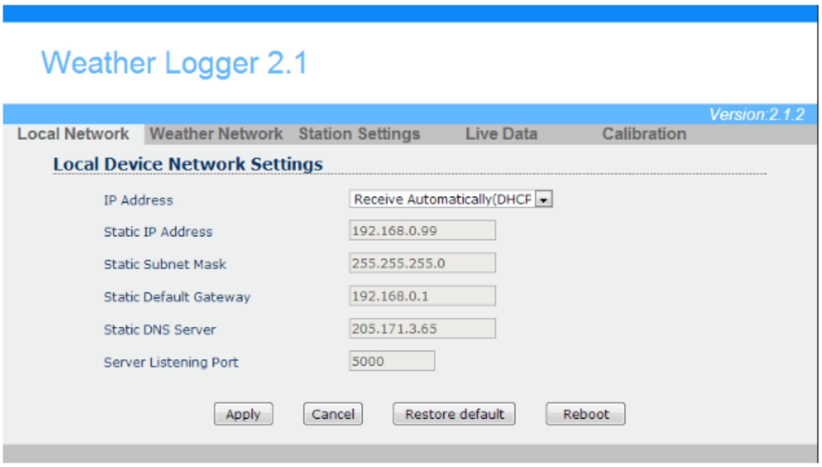


Figure 2.10 Weather logger

2.1.5 Check live data

Go to router menu and go to live data and see the values are updating per 30s interval.

Figure 2.11 Weather logger data checking

You can now provide EnviForecasting's iot server address in the station setting so that your data will be saved in its database and made available through APIs for raw data, tables or graphics

2.2 IoT server and Data Dissemination

The weather stations set up as outlined in the previous section now reports to the EnviForeasting IoT server and is available to the APN project. Currently 3 weather stations are deployed in the University of Peradeniya, Sri Lanka, Colombo, Sri Lanka and in Tokyo, Japan. The data from the weather stations are made available either as graphics or data tables as shown in the following figures. The plots of last one hour data, last 12 hour data or last 24 hour data can be readily viewed as shown below, through the following url: http://www.enviforecasting.com/apn

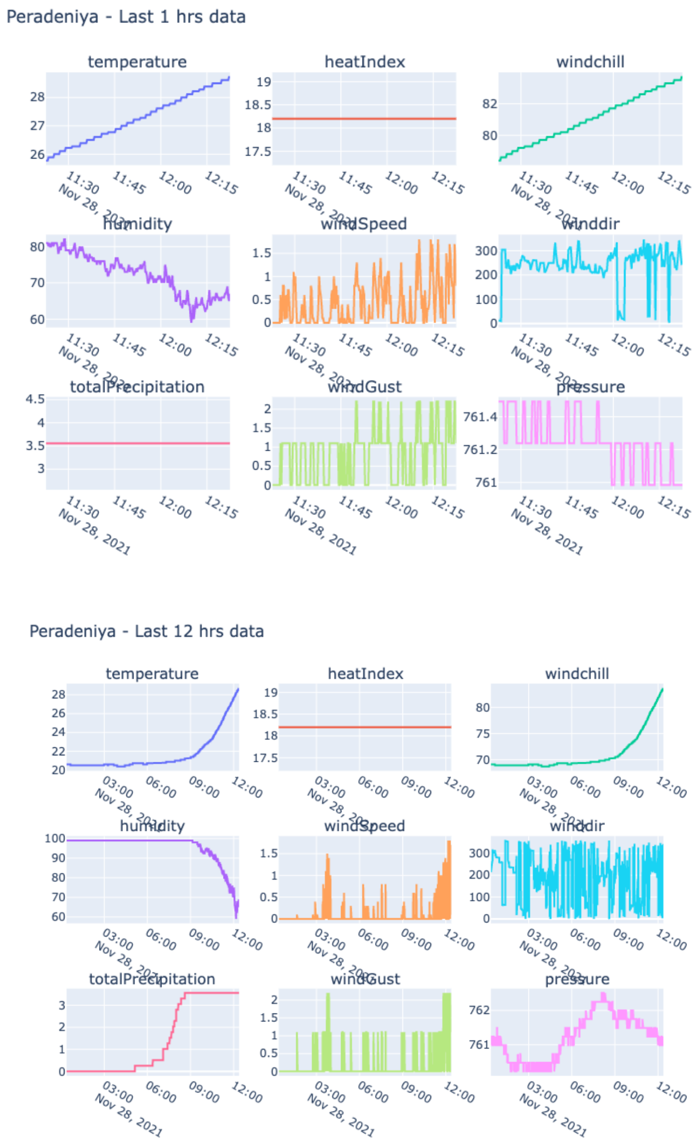


Figure 2.12 Plots of last one hour data (1)

Figure 2.13 Plots of last one hour data (2)

An alternative data interface for data visualization is shown below.

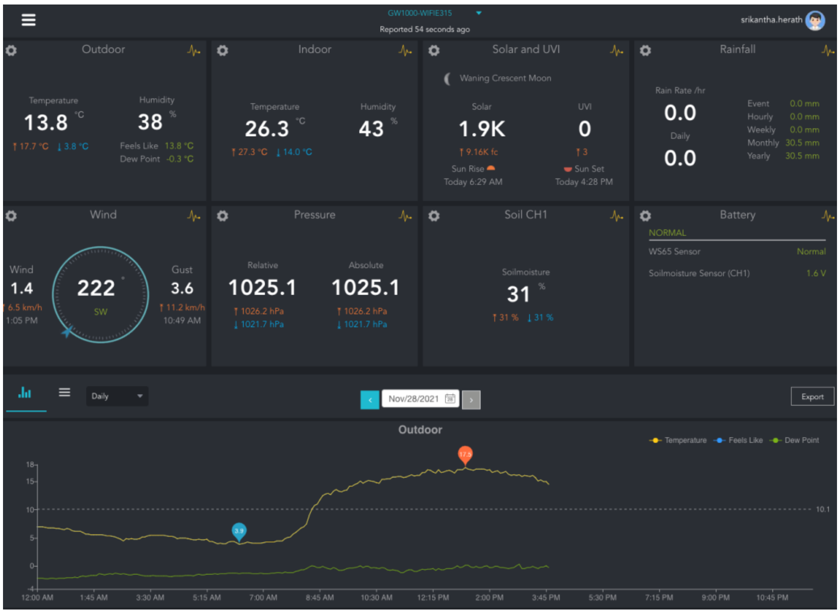


Figure 2.14 An alternative data interface for data visualization (1)

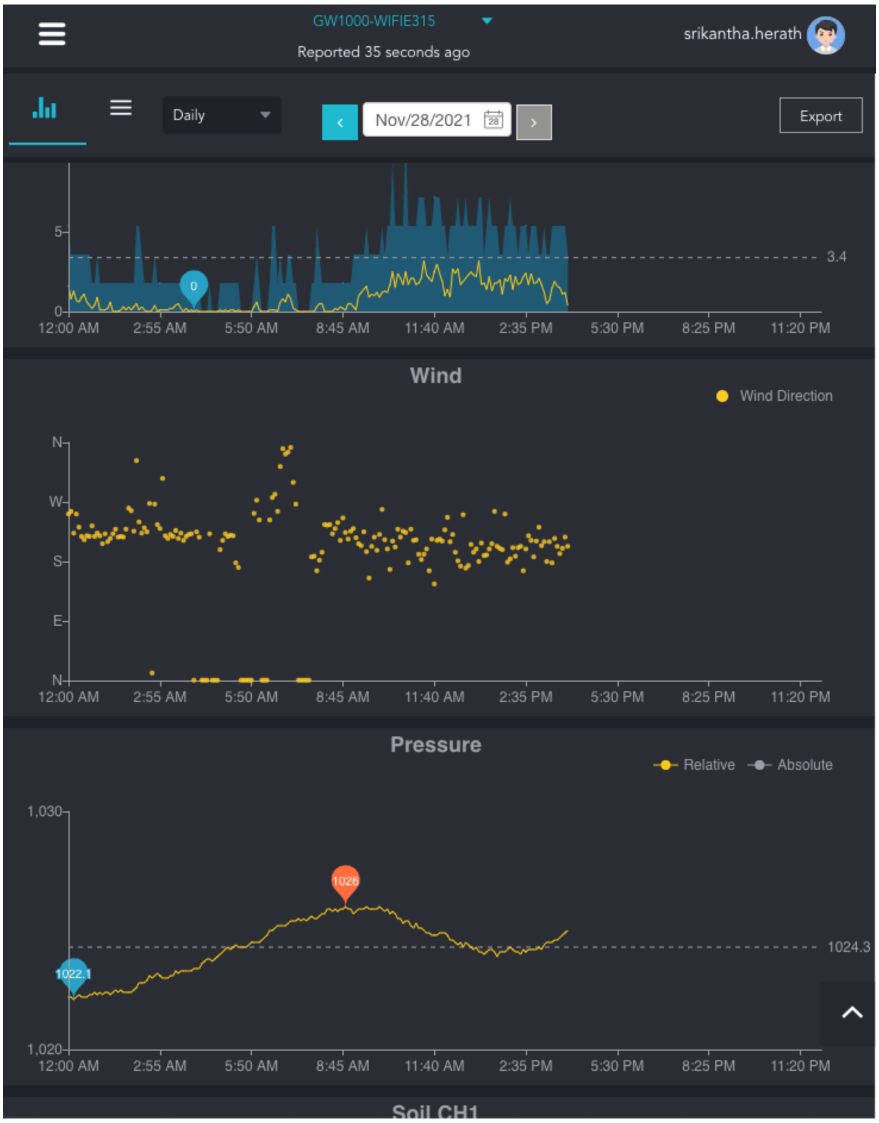


Figure 2.15 An alternative data interface for data visualization (2)

Data also can be downloaded as tables through the provided interface.

A typical data set is shown in the following table. Data are reported roughly every 15 seconds and the following table covers about 2 mins of duration.

Table 2.2 A typical data set table.

Time (UTC)	Time (Local)	Windspeed	Humidity	Temperature	Heat Index	Wind Chill	Wind Gust	Total Rain	Pressure
2021-11-28 07:16:11	2021-11-28 12:46:11	0.000000	66.0	29.1111	18.2	84.4	0.00000	3.556	760.984
2021-11-28 07:16:27	2021-11-28 12:46:27	2.101090	65.0	29.1111	18.2	84.4	3.40197	3.556	760.984
2021-11-28 07:16:43	2021-11-28 12:46:43	0.701853	64.0	29.1111	18.2	84.4	1.09972	3.556	760.984
2021-11-28 07:16:59	2021-11-28 12:46:59	0.701853	64.0	29.1111	18.2	84.4	1.09972	3.556	760.984
2021-11-28 07:17:15	2021-11-28 12:47:15	1.698750	65.0	29.1111	18.2	84.4	2.19944	3.556	760.984
2021-11-28 07:17:31	2021-11-28 12:47:31	1.502050	61.0	29.1111	18.2	84.4	2.19944	3.556	760.984

Application Programming Interface (API) is provided so that data can be directly obtained from the server as JSON structures shown below.

{"heatIndex":18.2,"humidity":61.0,"pressure":760.73,"station":"IPENID1","temperature":29.0, "timeLocal":"Sun, 28 Nov 2021 12:54:27 GMT","timeUTC":"Sun, 28 Nov 2021 07:24:27 GMT","totalPrecipitation":3.556,"windGust":1.09972,"windSpeed":0.0983488,"windchill":84.2 }

Appendix 3 Rainfall Discharge Data for Kelani River Basin and Analysis of recent extreme events.

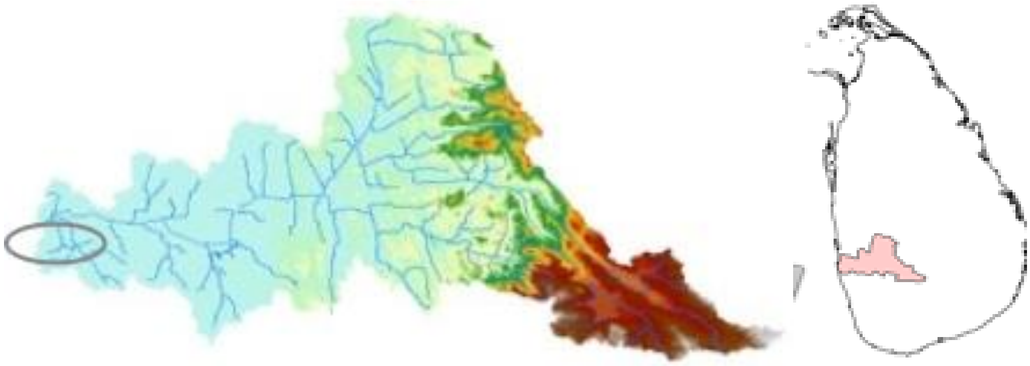
3.1 Kelani Basin Description

The Kelani River basin, where Colombo City is located, is the second largest river basin in Sri Lanka and is located between the Northern latitudes of 60 47' - 70 05' and Eastern longitudes of 790 52' - 800 13'. The River originates about 2250 m above mean sea level and passes 192 km through four districts of the country namely, Nuwara- Eliya, Kegalle, Gampaha, and Colombo before it reaches to the Indian Ocean. The basin area is about 2230 km^2. The basin can be considered to consist of two distinct sub-basins: the upper basin, which is mountainous and the lower basin, which is below Hanwella, has plain features. The Kelani basin receives about 2400 mm of annual average rainfall. The river flow, which mostly depends on the season, and the three operational reservoirs, is an average of $25m^3/s$ in dry periods and ranges between $800m^3/s$ and 1,500 m3/s during rainy seasons.

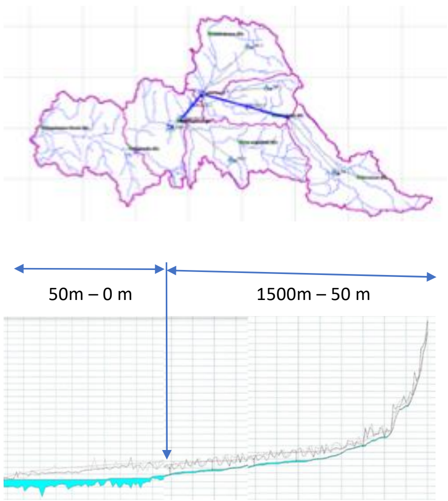
The Kelani River is fed by several tributaries. The Wak-Oya, Seethawaka River, Gatahatta Oya, Kehelgamu Oya, Maskeliya Oya, and Gurugoda Oya drain the upper basin while Attanagalu Oya, Maha Ela, and Pallewela Oya drain the lower basin. Moreover, the Kelani River is utilized for producing hydropower, using Mausakelle, Castlereigh, and Lakshapana reservoirs. Although Colombo City basin is part of the Kelani River Basin, it is protected from river overflow from a series of bunds and gates. City flooding occurs due to high-intensity rainfall within the catchment that cannot be drained adequately. There are two major challenges in reducing risk in Colombo.

- The City drainage depends on outfalls to the Kelani River as well as to the sea. The Kelani river outfalls cannot function when the Kelani river flows are high. Of the 8 major extreme rainfall events during the past 32 years, 4 have coincided with high Kelani River water levels.
- The terrain is extremely flat, and flooding occurs locally before drainage, even with pumps, becomes effective. Thus, high density rainfall measurements as well as rainfall forecasting is extremely important to prepare for extreme events.

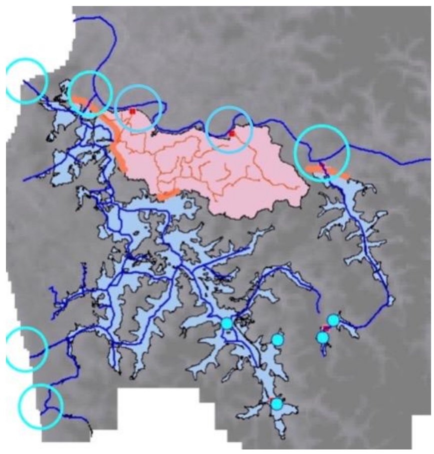
The basin, river profile and the city drainage networks are shown in the following figures



Kelani River Basin and its Location in Sri Lanka



River profile and Elevation drop



Urban Drainage Network

Figure 3.1 Colombo City located downstream of Kelani Basin and its outfalls to river and to the sea

The rainfall data from the weather station network deployed by the Center for Urban Water (CUrW), Sri Lanka, was used in the study to analyze the extreme rainfall conditions in the basin. The weather station network has been deployed under the Metro Colombo Urban Development Project funded by the World Bank. The weather data are freely available from the http://pub.curwsl.org website. The weather station network is shown in the figure below.

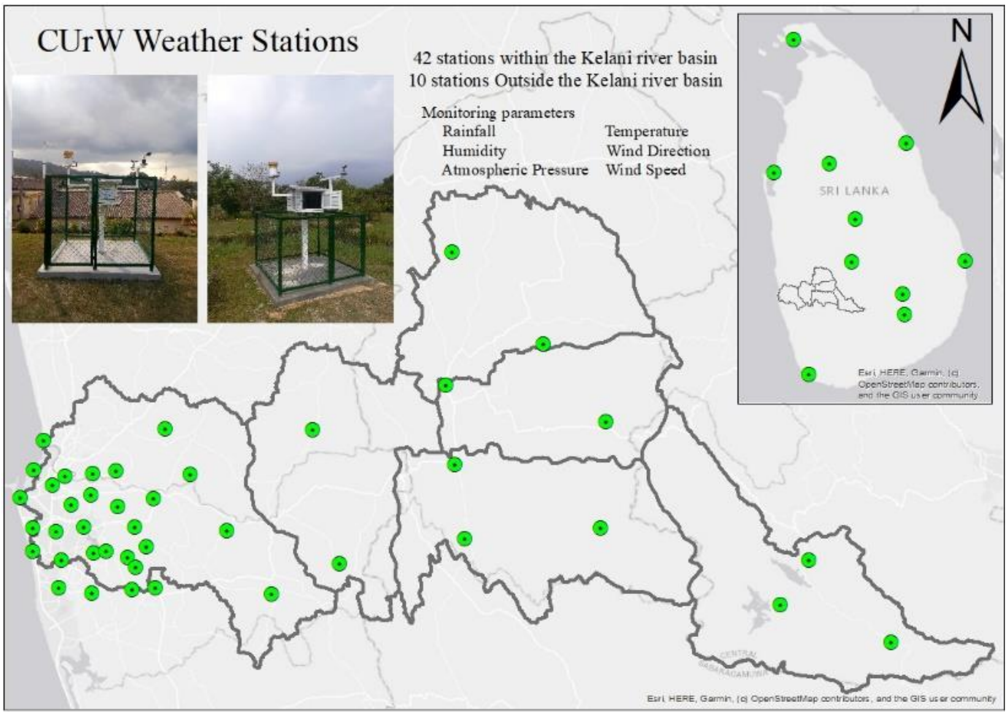


Figure3.2 Weather Station Network of Center for Urban Water

3.2 Real time Hydrology Dashboard

Using the tools and routines available in the enviForecasting platform, a dashboard to investigate and analyze the hydrometeorological behavior of the Kelani basin and Metro Colombo area was developed. The dashboard can show the current distribution of rainfall, the catchment response as given by the water level change data, and historical extremes of the year.

Rainfall and catchment response can be observed from the observation summary page shown in the Figure (3.3) below. It shows the cumulative rainfall at each weather station and the range of water level fluctuation within the city drainage network as well as the Kelani River that drain the main catchment. In addition to the summary of the total rainfall and the minimum and maximum water levels, the page also provides time series variation of accumulated rainfall as well as water level graphs over a specified 24-hour period. Unlike conventional webpages, this interactive page allows user to specify whether most recent data should be displayed or a data pertaining to a specified time. In the figure given below, the rainfall from November 27 midnight to 28 midnight is shown. As can be seen the heavy rainfall occurred not in the downstream of the catchment where Colombo City is located, but on the upstream of the basin.

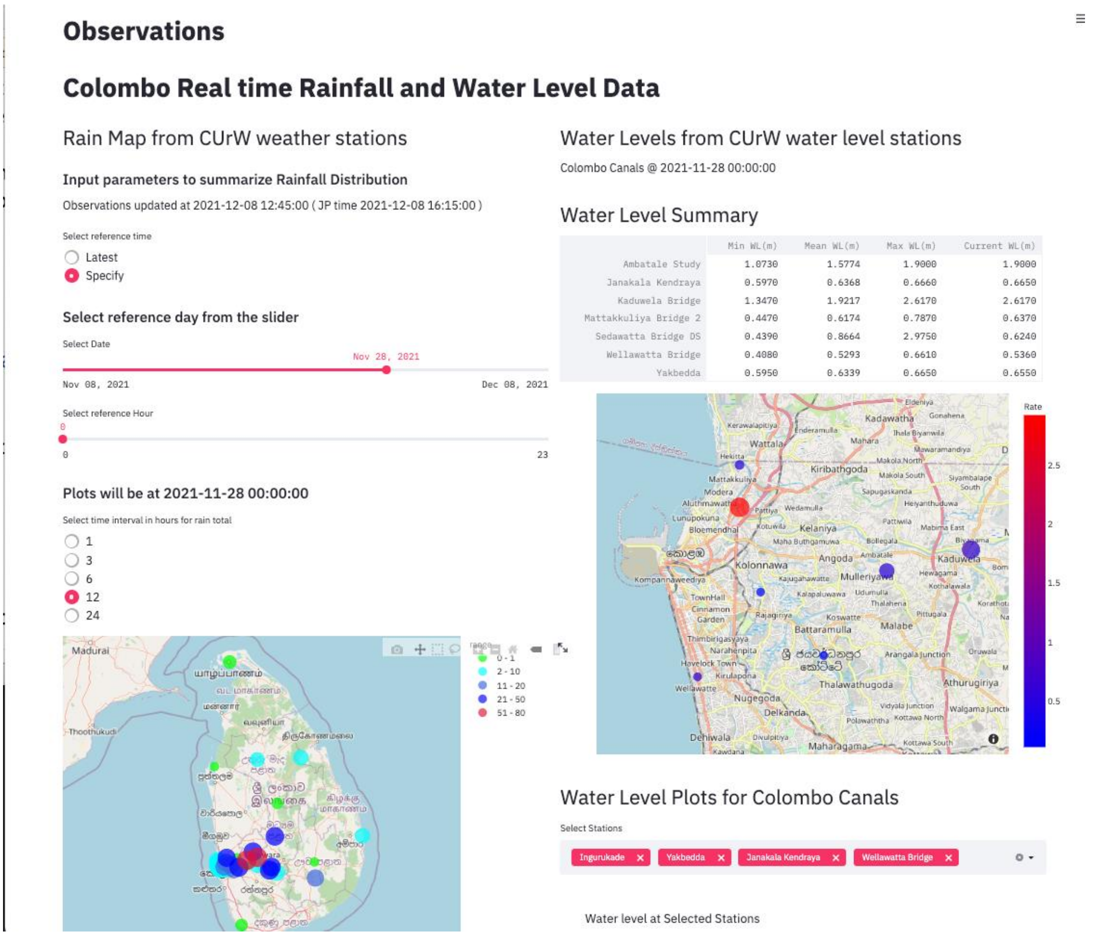


Figure 3.3 Upper portion of the dashboard figure showing rainfall and water level summaries

The catchment response to this rainfall can be observed from the water levels shown on the same page, shown in figure (3.4) below. It shows the cumulative rainfall in the upstream of the catchment reached a value of about 70 mm from the rainfall from 17hrs of 27th to about 21 hrs of the same date. In comparison downstream received only about 10 mm of rainfall. Thus, the water level at Parliament Lake in the city remained almost constant at around 0.65 m, whereas at Kaduwela station of the river, just upstream of the city, water levels started to rise above normal levels around midnight on 27th November. As Kelani basin is a rather large river basin there is a significant lag time between the peak of rainfall and the peak of river discharge. This is made clear in the water levels of the next day, November 28th as shown in Figure (3.5)

As can be seen from figure (3.5) there was no significant rainfall on the 28th. However, the Kaduwela station on the main river, above the city, peaked around 10 am, from the rainfall that peaked around 19hrs on the 27th. Thus, it is clear that there is a clear lag time for the river water level to rise from a heavy rainfall in the upstream of the catchment. It is about 15 hours till to the Kaduwela station and will take a few hours more to reach the city. This gives sufficient time to close the gates to the city to prevent city flooding from an overflow of the river flow.

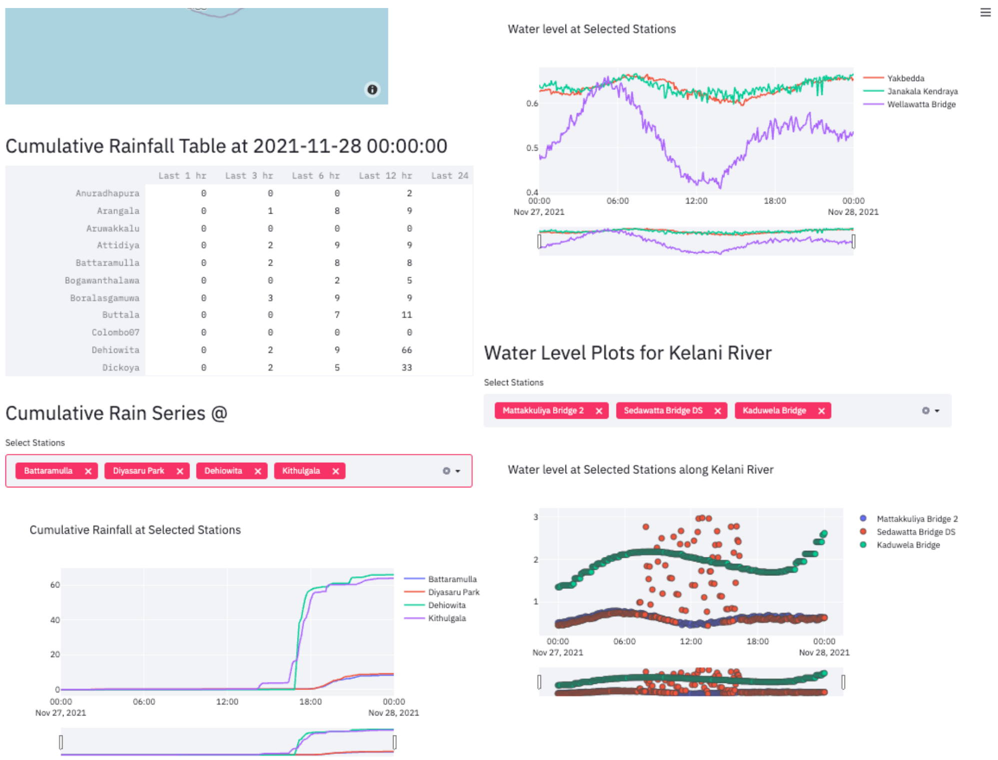
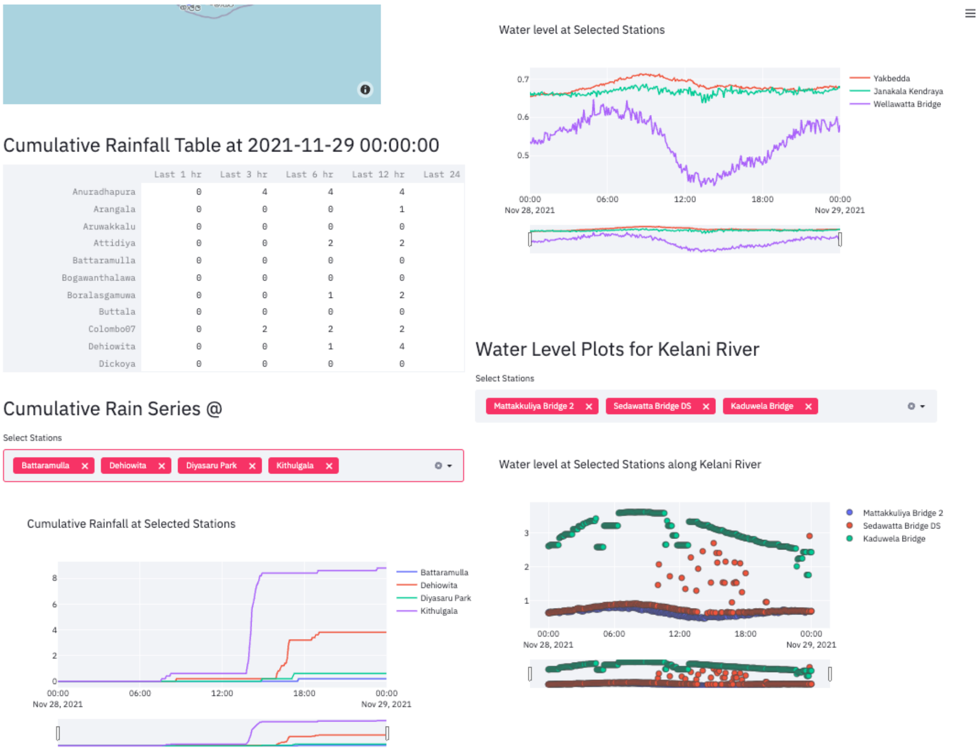


Figure 3.4 Lower part of the dashboard page that shows the time series variation of cumulative rainfall and water level changes of upstream and downstream stations.



	Last 1 hr	Last 3 hr	Last 6 hr	Last 12 hr	Last 24
Anuradhapura	0	4	4	4	
Arangala	0	0	0	1	
Aruwakkalu	0	0	0	0	
Attidiya	0	0	2	2	
Battaramulla	0	0	0	0	
Bogawanthalawa	0	0	0	0	
Boralasgamuwa	0	0	1	2	
Buttala	0	0	0	0	
Colombo07	0	2	2	2	
Dehiowita	0	0	1	4	
Dickoya	0	0	0	0	

Figure 3.5 the water levels and Cumulative rainfall on the 28th of November for the catchment.

In comparison to the river response, there is hardly any lag time between a high rainfall in the city and corresponding water level rise in city water ways. This is examined in the following section looking at high rainfalls experienced in the city. Extreme rainfall events in 2021.

3.3 Extreme Rainfall Events in 2021

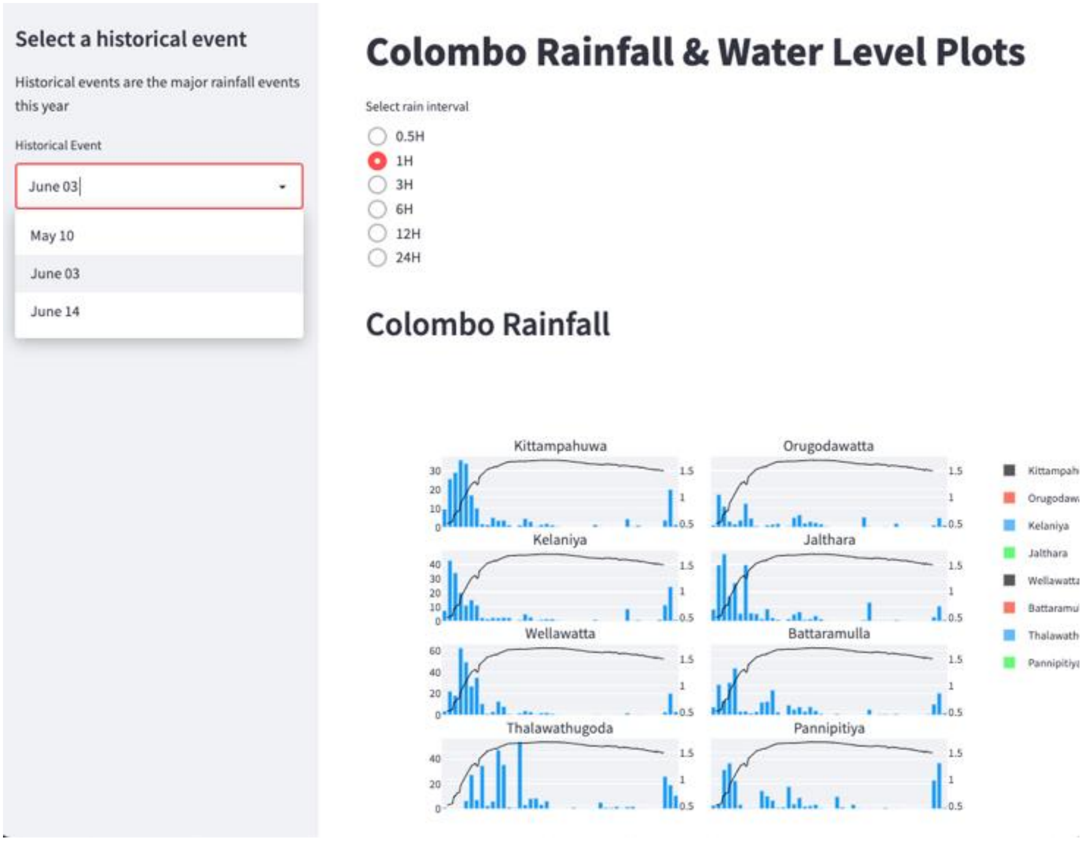


Figure 3.6 Past event display facility

The dashboard provides means to retrieve, plot and study extreme rainfall events. The facility is shown in Figure (3.6). Once a rainfall event is selected, rainfall event summarized a frequency the user needs and the corresponding data can be visualized for all hydrological stations. The frequency of the underlying data is 5 min.

3.4 Heavy Rainfall Event on June 03, 2021

From the available records the highest water levels in the city were observed due to the heavy rainfall in 2021 June 03. The water level in the Parliament Lake rose to 1.7m, due to a heavy rainfall that took place between noon to around 6 pm on the 23rd. The peak water levels were observed around 9.30 -10.00 pm. The 6 hourly rainfall summaries are a good indicator to understand flooding potential in the city. The Figure (3.7) shows rainfall distribution observed at some of the hydrological stations. As can be seen from the histogram, 7 stations out of 8 stations showed more than 100 mm of rain in 6 hours and 3 cases of more than 150 mm rain fall. The peak water level was reached around 22 hrs, 4 hrs after the heavy rainfall. As the rainfall eased, the water levels eased around 1.7 m. At 1.95 m, widespread flooding could have occurred.

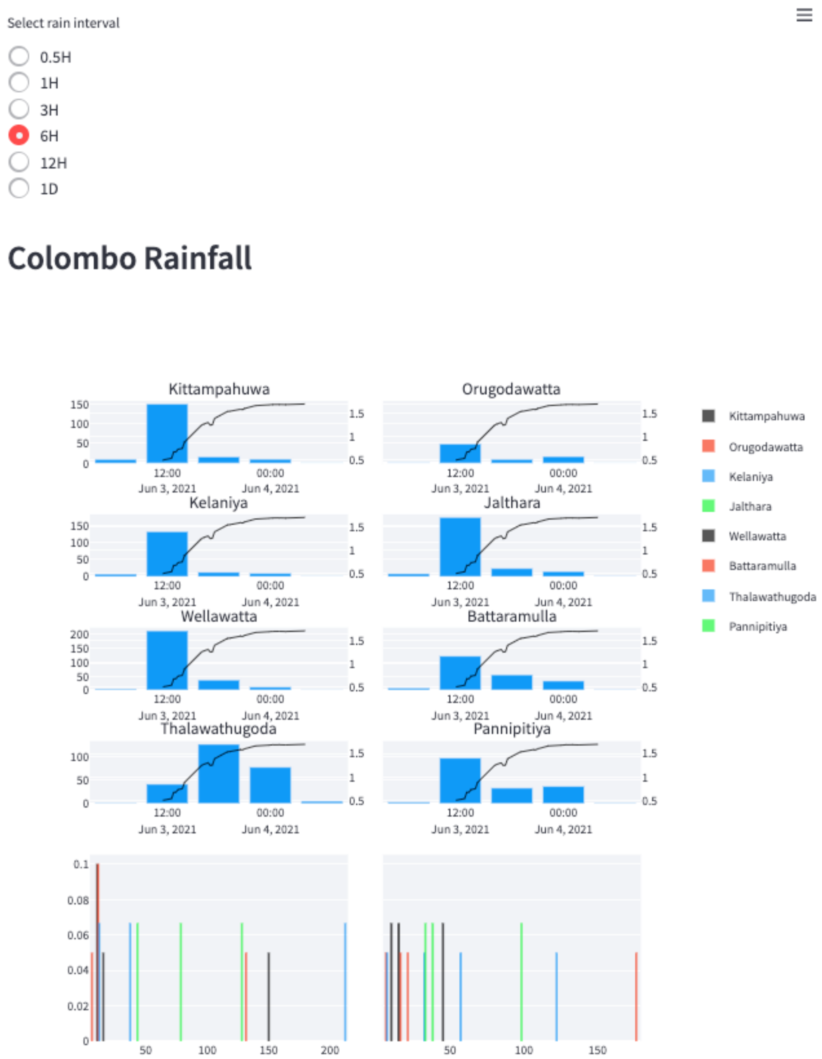


Figure 3.7 Rainfall (6 hr duration) and water level and Rain Histogram for the June 03 event

The dashboard further provides facilities to analyze observed data at different frequencies and compare different events so that stakeholders can become familiar with extreme events and form strategies to reduce loss and damage. The Figure 3.8 shows the rainfall distribution when viewed at hourly rainfall values. As many flood managers and hydrologists are familiar with the relation between rainfall intensities and potential flooding events, facilities summarize and view rainfall at different intensities can provide an insight to expected flooding conditions. The Figure H6 shows the same event if viewed as hourly rainfall series.

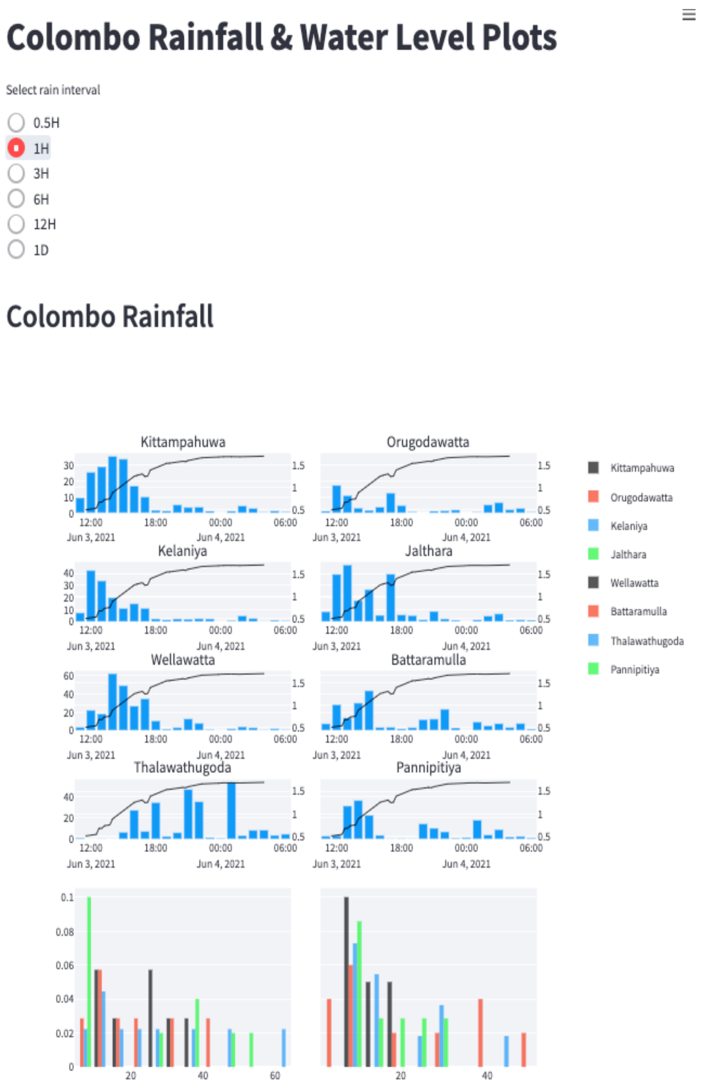


Figure 3.8 Rainfall (1 hr duration) and water level and Rain Histogram for the June 03 event

A review of rainfall runoff processes in Colombo and Kelani basin shows that real time observations may provide a sufficient lead time to prevent flooding in the city from Riparian floods from Kelani River, the lead time available for city flood prevention is not adequate if only rainfall observations are used for the purpose. Therefore weather and rainfall forecast accuracy need to be improved to address city flood disaster reduction. The next section will detail the facilities provided by the system to conduct weather forecasts and access accuracy based on the real time observations.

Appendix 4 Weather forecast using WRF model and Comparison of Results

4.1 Forecasting heavy precipitation events during Northeast Monsoon in BADULU OYA catchment using the WRF-ARW Model

Sri Lanka is a South Asian country which is located within the tropics between 50 55’ to 90 51’ North latitude and between 790 42’to 810 53’ East longitude in the Indian Ocean. Development of extreme low pressure conditions in the Bay of Bengal creates notable rainfall pattern variations across the island which experiences two distinct climate seasons as Northeast monsoon season (December-March) and Southwest Monsoon season (May-September). Mahaweli River is the longest river in Sri Lanka and Badulu Oya catchment is one of the sub-catchments of the Upper Mahaweli catchment area. The entire catchment covers 404 km2 land area within Badulla District. Badulu Oya is originated from Namunukula mountain range and it traverses approximately 59 km through eastern slopes of the central highlands (Figure 4.1). This river catchment receives major rainfall during the Northeast monsoon season (October- March) which is easterly disturbances. Mesoscale weather features of the Northeast monsoon are more dominant than synoptic scale features due to weak northeasterly wind flow and weak large-scale pressure gradient. Annual rainfall is approximately 1500 mm/year – 2000 mm/year within the catchment (Ruwangika, et al., 2020). Both riverine area and hill stream area are heavily used to cultivate seasonal vegetable crops while remaining area of the catchment is occupied by tea plantations and paddy lands in a greater extend. Badulu Oya covers a few main urban areas furnishing domestic water requirements, especially the middle part of the steam being densely populated (Rajapaksha, et al., 2020).

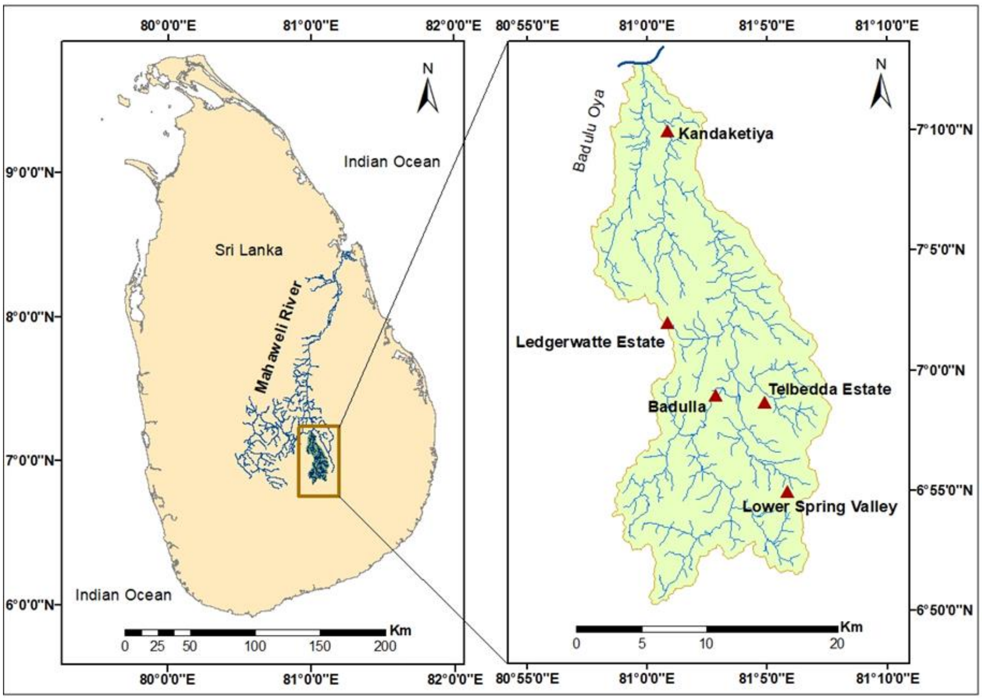


Figure4.1 Badulu Oya catchment and selected rainfall stations, Source: Department of Survey, Sri Lanka.

According to the statistics, Asia-Pacific region is considered as one of the most disaster-prone regions in the world (Report on disaster mitigation in Asia and the Pacific, 1991). Sri Lanka is prone to affect by severe tropical storms that caused widespread flooding and landslides in the country, destroying dwellings and submerging entire villages. The landslides in the island spread over about 30% of land area and into several districts and Badulla district is more prone for landslides compared to other districts in Sri Lanka (Jayasinghe, et al., 2017). In Sri Lankan contest, rainfall can be considered as a main landslide triggering factor. Generally, a continuous rainfall about 200 mm within a period of 3 days makes hilly districts susceptible to landslides. However, around two-day continues 75 - 100 mm rainfall can trigger landslides in sloped cultivated lands in Badulla district (Perera, et al., 2017). Hence, Badulu Oya catchment area within Badulla district is the major area where large-scale landslides are observed during heavy rainfall. These landslides cause major threats to the country’s economy through most damages in terms of economic impact and human casualties in every year.

In December, 2019, unexpected huge precipitation events were recorded in Badulu Oya catchment area with the North-East monsoon which were recorded as 100-140 mm large cumulative rainfall per day. These events instigated severe damages for residential people within the Badulu Oya catchment area (MINISTRY OF DEFENCE, 2019). The dates and recorded maximum daily rainfall amounts within the study area were: 1–8 December 2019 (130 mm) and 15–22 December 2019 (135 mm) (Department of Meterology, Sri Lanka, 2020). This research study emphases on numerical simulation of these two extreme rainfall events within 2019 year: 1–8 December (First Rainfall Event) and 15–22 December (Second Rainfall Event).

The accurate prognosis is relevant at different temporal scales ranging from short and medium range (few hours to some days ahead) which can reduce the impacts from water related hazards and provide the basis for more effective water resources management. However, the forecasting task is more rigorous due to the complex interactions between the Earth and the atmosphere. There are well recognized Global Climate Models (GCMs) which have limited capability of approximating global atmospheric conditions with oversimplified physics, parameterized structures and coarser horizontal spatial resolution contest. Regional Climate Models (RCMs) of high spatial/temporal resolution and improved physics (such as convection) are dynamically coupled to GCMs products are more appropriate tools to overcome the GCMs limitations which are capable of resolving the regional features associated with topography, local climate and the associated precipitation (Srinivas, et al., 2013). Secondly, with the advent of recent high performance computing, RCMs are preferably used to simulate the climate at moderately high resolutions (Mukhopadhyay, et al., 2010).

One major RCM designed to combine the expertise and experience for mesoscale meteorology and land surface and climate science developed over the last several decades to simulate or predict regional weather and climate is WRF model (Weather Research & Forecasting model). This is an open source software and latest version is WRF version 4.1.3 model (2019). The WRF version 4.1.3 model has many options for physics schemes: microphysics scheme, cumulus scheme, land surface scheme, boundary layer scheme and long/short wave radiation schemes which can fine tune the model to suite to its regional operating environment (Nandalal, et al., 2012; Kumar, et al., 2008; Skamarock, et al., 2008). The WRF model has two dynamical cores, which include advection, pressure gradients, Coriolis, buoyancy, filters, diffusion, time stepping etc. They are Advanced Research WRF (ARW) and Nonhydrostatic Mesoscale Model (NMM). Both are Eulerian mass dynamical cores with terrain-following vertical coordinates. Both WRF-ARW and WRF-NMM are mostly used in the atmospheric physics/parameterization research, real-time and forecast system research and data assimilation research. The WRF-ARW is only used in the regional climate and seasonal time-scale research, coupled-chemistry applications, global simulations and idealized simulations at many scales (e.g. convection, baroclinic waves, and large eddy simulations) (Dudhia, J, n.d.).

The microphysics and cumulus parameterization schemes directly affect the prediction of precipitation in the WRF model. The microphysics includes certain water vapor, cloud and precipitation processes while cumulus parameterization schemes are responsible for the sub grid scale effects of convective and/or shallow clouds and theoretically valid only for coarser grid sizes. According to study of Chawla, et al., (2018), spatial pattern of rainfall appears to be sensitive to the microphysics, while the amount of rainfall is more dependent on the cumulus and planetary boundary layer scheme options (Chawla, et al., 2018). Activating the cumulus scheme in the high-resolution inner domain improves the precipitation forecasting skill explicit microphysics alone (Sun & Barros, 2014; Lee, et al., 2011).

In the previous literature, Darshika & Premalal, (2015) have attempted to forecast heavy rainfall events in 2014 using the WRF model all over Sri Lanka and all their simulations underestimated the rainfall distribution which do not provide the best model simulation to predict rainfall maxima over Sri Lanka (Darshika & Premalal, 2015). Rodrigo, et al., (2018) simulated several tests in WRF model to identify the best model setup for predicting two heavy rainfall events in the two monsoon seasons all over Sri Lanka and concluded that their model outcomes were not estimate rainfall amount accurately and rainfall patterns were tally with some model configurations (Rodrigo, et al., 2018). The lack of studies on WRF model simulation relevant to the Badulla Oya catchment area is a major reason for this study. Therefore, this study is very important for both operational use and future research studies pertaining to rainfall forecasting using the WRF model. Accuracy of location and amounts of precipitation was examined using the deterministic approach considering a categorical verification method as well as two continuous verification methods by comparing the simulated 24-hour precipitation output with the observed 24-hour precipitation amounts. The developed model can be further improved for real-time forecasting with the aid of real-time observation network

4.2 Methodology and model description

The WRF-ARW model is a free and shared resource with distributed development and centralized support. This software has multi-nest capability, and several physics options for boundary layer processes, radiation schemes, cloud microphysics, and cumulus parameterization schemes. Total fifteen numbers of physics scheme combinations were selected to evaluate a series of mesoscale simulations with various parameterization schemes, especially considering the studies which are conducted in Sri Lanka. The default configuration of WRF-ARW uses Yonsei University planetary boundary layer scheme (Hong, et al., 2006), RRTM longwave radiation scheme (Mlawer, et al., 1997), Dudhia shortwave radiation scheme (Dudhia, 1989), Unified Noah land surface scheme (Mukul Tewari, et al., 2004), Revised MM5 surface layer scheme (Jiménez, et al., 2012) which were not changed within the selected combinations. The microphysics & cumulus schemes were changed among the models which are sensitive to the numerical weather prediction over tropical areas (Nandalal, et al., 2012). Eta (Ferrier) scheme (Rogers, et al., 2001), WRF single–moment 3–class scheme (WSM3) (Han & Hong, 2018), WRF single–moment 5–class scheme (WSM5) (Hong, et al., 2004), WRF single–moment 6–class scheme (WSM6) (Hong & Lim, 2006), Kessler scheme (Kessler, 1969), WRF double moment 6–class scheme (WDM6) (Lim & Hong, 2010) were selected as microphysics schemes for the study. Kain–Fritsch scheme (KF) (Kain, 2004), Betts–Miller–Janjic scheme (BMJ) (Janjić, 1994), Multi–scale Kain–Fritsch scheme (MKF) (Zheng, et al., 2016), Grell–Freitas Ensemble scheme (GF) (Grell & Freitas, 2014) were used as cumulus schemes for the tested combinations. The tested physics scheme combinations with interchanging the selected microphysics scheme & cumulus schemes along the default remaining schemes are listed in bellow Table 4.1. Same physics schemes were inserted into all the nested domains for a given model simulation in an attempt to minimize inconsistencies at the interface of the computation grids (Warner, et al., 1997).

Table 4.1 Proposed physics combinations for the research study

Reference Number	Microphysics Scheme	Cumulus Scheme
CM1	Ferrier	KF
CM2	WSM3	KF
CM3	WSM5	KF
CM4	WSM6	KF
CM5	Kessler	KF
CM6	Ferrier	BMJ
CM7	WSM3	BMJ
CM8	WSM5	BMJ
CM9	WSM6	BMJ
CM10	Kessler	BMJ
CM11	WDM6	MKF
CM12	WSM6	MKF
CM13	WDM6	GF
CM14	WSM6	GF

CM15	WDM6	KF

The domains setup has 27 km horizontal resolution in its mother domain and 1, 3, 3 parent grid ratios with the remaining domains. Horizontal and vertical grid points of this domain configuration were selected as 100 x 100, 100x 100 and 34 x 34 respectively. Domain setups is two-way nested which were selected to cover the entire Bay of Bengal while placing Sri Lanka at the center based on the significant effects of low pressure systems in the Bay of Bengal to the heavy precipitation in Sri Lanka (Silva, et al., 2016) and share the same center (Badulla town) in the Mercator projection system and geographic data resolution is taken as 30 s. The inner grid covers the Badulu Oya catchment, and only the meteorological information from the inner grid was used in this research study.

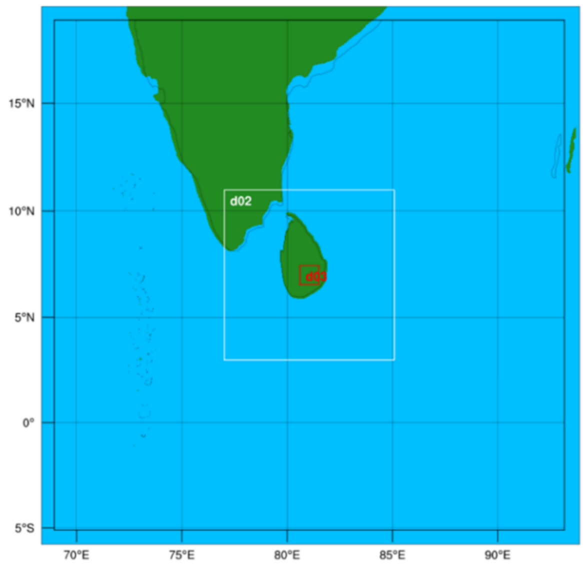


Figure 4.2 WRF domain setup; three domains setup (3 km)

Recorded two extreme rainfall events which caused numerous damages within 2019 year were selected for this study: 1–8 December (First Rainfall Event) and 15–22 December (Second Rainfall Event). The selected events were simulated in WRF-ARW software for 8 days period where first day (24 hours) was run as the spin-up period to establish the model. The models were initialized at 0600 UTC and rainfall periods of 24 h ending at 0600 UTC in each day. This is the same as 24 h rainfall criterion used in the Department of Meteorology, Sri Lanka while considering time gaps of the original field recording time (0300 UTC). Boundary conditions for the finer domain was updated every 6 hours from the NCEP FNL (Final) dataset (National Center for Atmospheric Research, 2019). Various terrestrial datasets were given from the WRF users' website, which is the most commonly used dataset for the WRF model simulations (National Center for Atmospheric Research, 2020). It should be noted that each model combinations used identical configurations and initialization data, other than slightly different domain resolution and parameterization schemes. Modelling is compiling the WRF-ARW software was conducted by referring WRF-ARW Online Tutorial (UCAR, 2016).

All the proposed combinations (CM1 – CM15) were run for the selected two rainfall periods separately within December, 2019 month (thirteen model runs). Best five performed combinations were selected as the initial matching forecast models for the study area. These were presented as the final matching forecast models for the study area. To verification & validation of the selected final five best models, these models were tested for the two North-East monsoon rainfall events: 21–28 December, 2018 and 17–24 December, 2020. Finally the obtained results were compared and presented with recommendations in this research paper.

4.3 Model Results Comparison

Current active five rain gauging stations within the Badulu Oya catchment including Kandaketiya (7.167 N, 81.017 E), Ledgerwatte Estate (7.033 N, 81.017 E), Badulla (6.983 N, 81.050 E), Telbedda Estate (6.978 N, 81.084 E) and Lower Spring Valley (6.917 N, 81.100 E) were selected for the study (Figure 1). The observed daily precipitation data of the selected five stations was obtained by contacting the Department of Meteorology, Head Office, Colombo. Among these stations, 3 hours period, automatic rainfall values recording facility is only available in Kandaketiya and Badulla stations while remaining stations have only the standard manually operated rain gauges. All rainfall observations are for the accumulative rainfall at 0300 UTC according to the Department of Meteorology. But, there are time gaps of this selected recording time (0300 UTC) while collecting the field precipitation measurements. The accumulative precipitation is measured up to the first decimal place of a millimeter from the standard manually operated rain gauges. These surface observations were used as ground-truth observations in the study.

Once the WRF model grid point values were interpolated and extracted to each observation location, the quality of rainfall predictions were compared based on the deterministic approach considering categorical verification methods as well as continuous verification methods in this study.

4.4 Categorical verification

The joint distribution of forecast and observation can be described by the help of dichotomous categorical verification technique (contingency tables). Total number of 35 (5 x 7) data pairs relevant to the 5 rainfall gauging stations for 7 day period were evaluated using the 2 x 2 contingency table based on categories of forecast specified established on 24 h total precipitation accumulated thresholds; above 10 mm, 25 mm, and 50 mm. The observed daily rainfall data and the simulated data were evaluated to determine the proportion correct (PC), probability of detection (POD), false alarm ratio (FAR), bias (B) and Equitable Threat Score (ETS) for each threshold category across the entire domain (Wilks, 2011). The proportion correct (PC) determines the fraction of all forecasts that were correct which is sensitive to both hits and correct rejections. The value ranges between 0 and 1, and the perfect score is 1. The probability of detection (POD) displays the percentage of stations at which WRF correctly simulated precipitation when precipitation was observed which is also called the hit rate. The value ranges between 0 and 1 and the perfect score is 1. The false alarm ratio (FAR) determines the percentage of falsely simulated events of precipitation when compared to the total number of simulated precipitation events. The value varies between 0 and 1, and the perfect score is 0. The Bias (B) determines whether WRF simulated precipitation at more stations than observed, or fewer than observed. The value can range between 0 and infinity, and the perfect score is 1. The Equitable Threat Score (ETS) or Gilbert Skill Score determines overall skill when simulating precipitation, and includes a correction term which reduces the effect of a correct precipitation simulation by chance. An ETS score of 0 indicates the same accuracy as a random precipitation simulation, and positive ETS scores indicate some level of accuracy, while a perfect precipitation simulation would have ETS score equal to 1. To summarize all results related to the three rainfall thresholds, average values of the Equitable Threat Score (ETS) and the Bias (B) were employed to represent the overall performance of the model rainfall predictions. Appendix A contains formulas for the above precipitation statistics indices.

4.5 Continuous Verification- Normalized version of Taylor diagram

The normalized version of Taylor diagrams is most frequently used to illustrate the phase association (correlation) and amplitude (standard deviation) errors in the weather research forecasting field (NCAR, 2019). After obtaining forecasted 24 h accumulated rainfall at the five rainfall stations in the WRF output data, total number of 35 (5 x 7) data pairs relevant to the 5 rainfall gauging stations for 7 day period were used calculate the mentioned statistics indices.

These indices were presented graphically using the Taylor diagram after reviewing technical details at NCAR website (NCAR, 2019). In the diagrame, WRF models that tally well with reference will lie nearest the point marked “REF" on the x-axis. These WRF models will have relatively high correlation and low RMSE. WRF models lying on the dashed arc will have the correct NSD (which indicates that the model variations are of the right amplitude). Moreover, lower bias values indicates model results do not deviate extensively with observations.

4.6 Results and Discussion

4.6.1 First rainfall event

The WRF-ARW model was used to simulate the First Rainfall Event (from 1st to 8th of December, 2019) with the all proposed fifteen parameterization schemes combinations (CM1-CM15). The computed statistical indices in each accumulated precipitation thresholds were displayed in below Table 4.2. Overall the highest PC values are in the largest threshold; 50 mm. CM9 combination displays the highest PC values in both 10 mm (0.74) and 25 mm (0.83) thresholds while CM3 & CM11 record the highest PC value in 50 mm (0.94) threshold. CM12 has the highest POD value in both 10 mm (0.95) and 25 mm (1.00) thresholds. In the largest threshold, CM8, CM10 & CM12 have the largest POD value which is 1.00 which correctly recognized precipitation events. The lowest FAR value is in 10 mm (0.08) threshold belongs to CM5 while CM7 has the lowest FAR value in 25 mm (0.00) threshold due to falsely simulating lower precipitation events. CM3 & CM11both record the lowest FAR value in 50 mm threshold (0.17). The FAR value relevant to the CM7 in 50 mm threshold couldn’t be calculated due to both hits and false alarms are zero in the largest threshold category. CM1 & CM7 displays the lowest skill in each categories which have Ferrier & WSM3 microphysics respectively. Considering the overall statistical indices, CM9 & CM12 which include WSM6 micro physic scheme displays positive forecast skill among others in both 10 mm and 25 mm threshold categories. CM3 & CM11 which include KF & MKF cumulus scheme respectively record overall best performance in the largest threshold category. The overall performance of the first rainfall event analysis was identified using the average values of the Equitable Threat Score (ETS) and the Bias (B) related to the three threshold categories (Table 4.2). CM3 displays the best performance which has the largest ETS value (0.38) & bias value of 0.95. Next, CM4 records positive skill similar to the CM3 which has ETS value of 0.36 & bias value of 1.04. After the CM3 & CM4 combinations, CM11, CM9 & CM8 record good skill among remaining combinations which have ETS value of 0.31, 0.31, 0.34 & bias value of 1.03, 1.45, and 1.50 respectively. CM1 & CM2 are the poorest performed models which also agree with above each threshold categories findings which have Ferrier & WSM3 microphysics respectively. Considering the best performed two models, WSM5 & WSM6 micro physics schemes with KF cumulus scheme were able to simulate the first rainfall event more accurately than the other schemes combinations.

Following normalized Taylor diagram in Figure 3 displays the results relevant to the first rainfall event. CM3 model generally agree best with observation data, which has correlation coefficient about 0.76 units & lowest standard deviation difference. CM3 model also has correlation coefficient about 0.65 units & standard deviation difference about 0.92 units with observation data. In addition, both CM4 and CM3 have similar root mean square error values. Considering bias of these two models, CM4 (0.12) has the lower values than CM3 (10). Moreover, CM11 model also lies near the dashed arc, but it has higher standard deviation difference (0.82 with correlation of 0.72 and bias of -5.15) than CM3 & CM4 models. Poorer performing WRF models, CM5, CM6, CM8, CM9, CM10, CM12 & CM13 have standard deviation value more than 1.65. CM3, CM4, CM11 & CM14 displays positive performance in descending order respectively which also agree with above mentioned categorical verification findings.

Table 4.2 Statistical indices for the first rainfall event, December, 2019 for three precipitation thresholds. B and ETS are averaged values over three thresholds. Bold values indicate the most accurate tested physics combinations for the given analysis.

	PC			POD			FAR			B	ETS
Threshold (mm)	10	25	50	10	25	50	10	25	50		
CM1	0.60	0.51	0.77	0.77	0.58	0.00	0.35	0.63	1.00	1.03	0.01
CM2	0.54	0.60	0.80	0.59	0.25	0.00	0.35	0.63	1.00	0.58	0.01
CM3	0.63	0.77	**0.94**	0.64	0.67	0.83	0.26	0.33	**0.17**	**0.95**	**0.38**
CM4	0.63	0.80	0.91	0.64	0.75	0.83	0.26	0.31	0.29	**1.04**	**0.36**
CM5	0.69	0.80	0.74	0.55	0.67	0.33	**0.08**	0.27	0.71	0.89	0.24
CM6	0.69	0.57	0.46	0.73	0.58	0.17	0.24	0.59	0.93	1.62	0.06
CM7	0.69	0.69	0.83	0.59	0.08	0.00	0.13	**0.00**	-	0.26	0.10
CM8	0.71	0.80	0.80	0.73	0.92	**1.00**	0.20	0.35	0.54	1.50	0.34
CM9	**0.74**	**0.83**	0.69	0.73	0.92	0.67	0.16	0.31	0.69	1.45	0.31
CM10	0.71	0.71	0.80	0.73	0.92	**1.00**	0.20	0.45	0.54	1.58	0.30
CM11	0.60	0.69	**0.94**	0.68	0.58	0.83	0.32	0.46	**0.17**	1.03	0.31
CM12	0.69	0.69	0.74	**0.95**	**1.00**	**1.00**	0.32	0.48	0.60	1.94	0.22

CM13	0.57	0.69	0.74	0.64	0.67	0.67	0.33	0.47	0.64	1.35	0.15
CM14	0.63	0.60	0.80	0.86	0.83	0.83	0.34	0.55	0.55	1.66	0.17
CM15	0.69	0.74	0.86	0.59	0.50	0.33	0.13	0.33	0.33	0.64	0.24

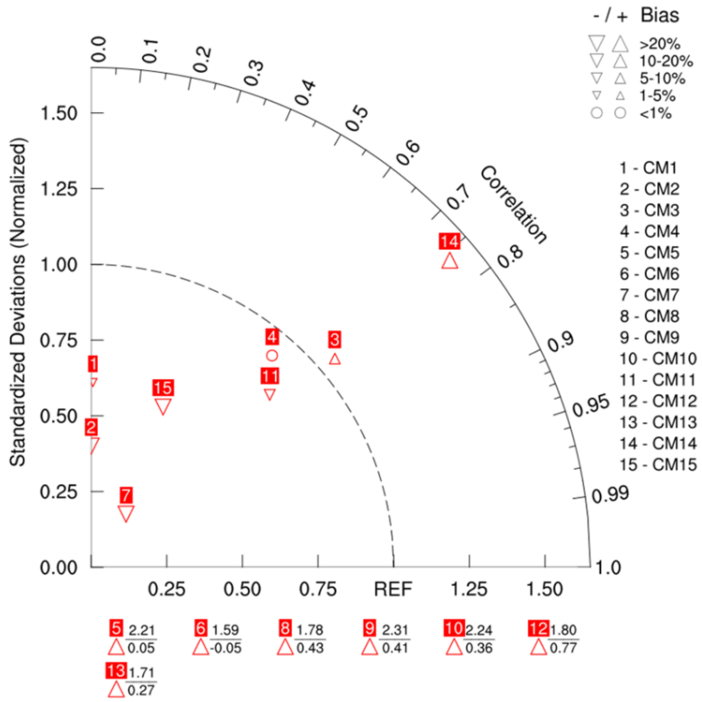


Figure 4.3 Normalized Taylor Diagram for fifteen models in the first rainfall event, December, 2019.

Negative correlations and standard deviations > 1.65 are displayed as text at the bottom of the figure. Upper value indicates the standard deviation while bottom value indicates the correlation coefficient.

4.6.2 Second rainfall event

The statistical indices in each accumulated precipitation thresholds categories for the second rainfall event were indicated in below Table 4.3. CM12 displays the highest PC value in 10 mm threshold category (0.80) while CM10 records the highest PC value in both 25 mm (0.69) and 50 mm (0.77) threshold categories. CM12 has the highest POD value in both 10 mm (0.91) and 25 mm (0.63) thresholds while CM14 has the highest POD value in 50 mm (0.46) threshold category. CM10 records the lowest FAR value in all the threshold categories (0.0) while CM8 also has the zero FAR value in both 25 mm and 50 mm threshold categories. The FAR value relevant to the CM5, CM6, CM9 in 25 mm threshold & CM3, CM4, CM5, CM6, CM9 in 50 mm threshold couldn't be calculated due to both hits and false alarms are zero during the calculation steps. CM1 & CM2 displays the lowest skill in each category which have Ferrier, WSM3 microphysics scheme with KF cumulus scheme respectively. Considering the overall statistical indices, CM9 & CM5 displays positive forecast skill among others in both 10 mm and 25 mm threshold categories which include WSM6, Kessler micro physic schemes with BMJ, KF cumulus schemes respectively. CM3

& CM11 which include KF & MKF cumulus scheme respectively have the overall best performance in the largest threshold category. Although, CM10 has the highest ETS value (0.19), it records considerably lower bias value (0.30) than CM12. Next, CM11, CM7, CM2 have good skill among remaining combinations which have ETS value of 0.15, 0.13, 0.13 & bias value of 0.54, 0.46, 0.39 respectively. Considering the calculated ETS and Bias values in the second rainfall event, the first rainfall event has higher ETS values and lower bias deviations which is resulted the higher predicting skill of the models for the first rainfall event than the second rainfall event. In addition, the first rainfall has higher bias values which exceed 1.0 (over forecasting) than the second rainfall event (under forecasting). CM6 & CM9 are the poorest performed models which have Ferrier & WSM6 microphysics with BMJ cumulus scheme respectively. Considering the best performed two models, WSM6 & Kessler micro physics schemes with MKF & BMJ cumulus schemes were able to simulate the second rainfall event more accurately than the other schemes.

Table 4.3 Statistical indices for the second rainfall event, December, 2019 for three precipitation thresholds. B and ETS are averaged values over three thresholds.

	PC			POD			FAR			B	ETS
Threshold (mm)	10	25	50	10	25	50	10	25	50		
CM1	0.51	0.63	0.71	0.43	0.25	0.23	0.29	0.20	0.00	0.38	0.11
CM2	0.66	0.66	0.63	0.57	0.31	0.08	0.13	0.17	0.50	0.39	0.13
CM3	0.57	0.54	0.63	0.52	0.19	0.00	0.25	0.50	-	0.36	0.04
CM4	0.57	0.54	0.63	0.52	0.19	0.00	0.25	0.50	-	0.36	0.04
CM5	0.43	0.54	0.63	0.13	0.00	0.00	0.00	-	-	0.04	0.02
CM6	0.34	0.54	0.63	0.04	0.00	0.00	0.50	-	-	0.03	0.00
CM7	0.54	0.63	0.71	0.43	0.31	0.31	0.23	0.29	0.20	0.46	0.13
CM8	0.54	0.66	0.69	0.39	0.25	0.15	0.18	**0.00**	**0.00**	0.29	0.12
CM9	0.46	0.54	0.63	0.30	0.00	0.00	0.30	-	-	0.14	0.01
CM10	0.49	**0.69**	**0.77**	0.22	0.31	0.38	**0.00**	**0.00**	**0.00**	**0.30**	**0.19**
CM11	0.69	0.60	0.69	0.65	0.25	0.31	0.17	0.33	0.33	0.54	0.15
CM12	**0.80**	0.60	0.63	**0.91**	**0.63**	0.31	0.19	0.44	0.50	**0.96**	**0.18**
CM13	0.51	0.57	0.54	0.48	0.38	0.08	0.31	0.45	0.80	0.59	0.01
CM14	0.57	0.49	0.60	0.70	0.50	**0.46**	0.33	0.56	0.54	1.06	0.03
CM15	0.63	0.49	0.57	0.65	0.25	0.00	0.25	0.60	1.00	0.55	0.01

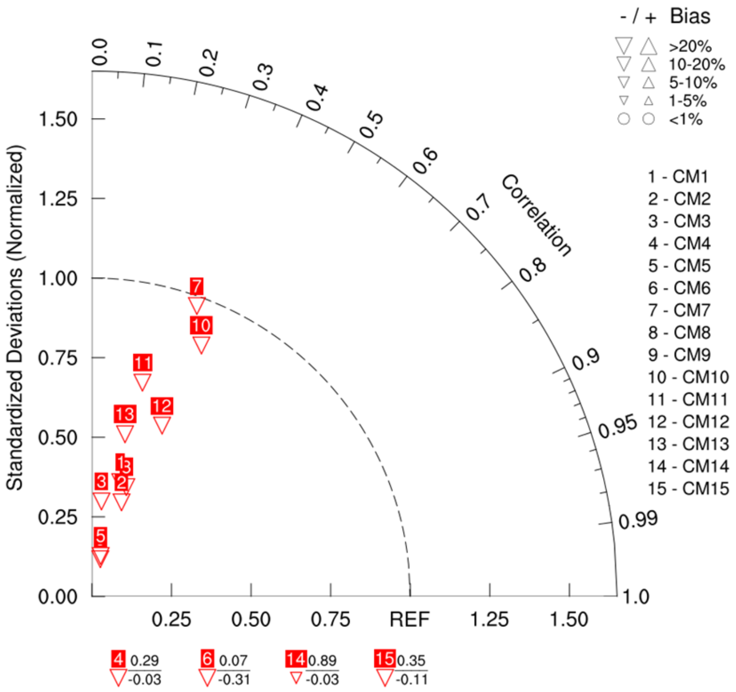


Figure 4.4 Normalized Taylor Diagram for fifteen models in the second rainfall event, December, 2019.

Negative correlations and standard deviations > 1.65 are displayed as text at the bottom of the figure. Upper value indicates the standard deviation while bottom value indicates the correlation coefficient. Above normalized Taylor diagram in Figure 4 displays the obtained results relevant to the second rainfall event. CM7 model generally agree best with observation data, which has correlation coefficient about 0.34 units & lowest standard deviation difference. CM10 model has the highest correlation coefficient about 0.40 units & standard deviation difference about 0.86 units with observation data. Considering bias of these two models, CM7 (-42.78) has the lower values than CM10 (-64.38) which have negative sign (underestimated). Poorer performing WRF models, CM4, CM6, CM14 & CM15 have standard deviation value more than 1.65. CM7, CM10, CM12 & CM11 displays positive performance in descending order respectively.

4.7 Summary of model training results

4.7.1 Model training results

The model training was conducted for the selected two rainfall events in December, 2019 month and predicting skill of the tested models were evaluated based on the deterministic approach considering categorical verification methods as well as continuous verification methods in above sections. Below Table 4.4 has a summary of findings from the conducted evaluation process. First four best performed model combinations which were identified in each verification methods relevant to the tested two rainfall events are presented in the below table. The selected combinations were ordered in descending order considering their identified performance skills in each verification methods.

Table 4.4 Summary of model training results. Bold values indicate the most accurate tested physics combinations for the given analysis.

	First Rainfall Event (1 to 8/12/2019)		Second Rainfall Event (15 to 22/12/2019)	
Order	Categorical verification	Taylor diagram	Categorical verification	Taylor diagram
1	**CM3**	**CM3**	**CM12**	CM7
2	**CM4**	**CM4**	**CM10**	**CM10**
3	**CM11**	**CM11**	**CM11**	**CM12**
4	CM9	CM14	CM7	**CM11**

Considering above obtained summary of model training results, CM3, CM4 & CM11 display positive skills than remaining tested model combinations for the first rainfall event simulation considering the outcomes of the conducted three deterministic approaches. In the second rainfall event simulation, CM10, CM11 & CM12 performed well than other models within the three deterministic approaches. Among these mentioned best model combinations, CM11 displays good performance in both first rainfall and second rainfall simulations. Finally, CM3, CM4, CM10, CM11 & CM12 model combinations were filtered which capable to achieve an improved station wise forecast within the North-East monsoon season over the Badulu Oya catchment.

Table 4.5 uses 2×2 contingency table for a dichotomous categorical verification of precipitation forecasts; where each element (a, b, c, and d) hold the number of observation stations relevant to the tested date in which the observation and simulation exceed or fail to exceed a precipitation threshold. For example, for a precipitation threshold of 10 mm, if there was 12 mm of observed precipitation (rain) at an observation station, and 8 mm of simulated precipitation (non-event) at the same observation station, this would be a miss (c), increasing the miss (c) counter by one.

Table 4.5 Statistical skill scores for evaluating the model performance using 2 x 2 contingency table

		Observed		Marginal Total
		Yes	No	
Forecast	Yes	A (Hits)	b (False Alarm)	a + b
	No	C (Miss)	d (Correct Rejections)	c + d
Marginal		a + c	b + d	a + b + c + d

For a given precipitation threshold, the statistical skill scores relevant to the categorical verification can be found for each rainfall event from the contingency table above. The details of the calculated statistical indices are displayed in below with their optimal values.

Table 4.6 The details of the calculated statistical indices

Indices	Aspects	Formula	Range	Optimal Value
Proportion Correct (PC)	Accuracy	$\frac{a+d}{n}$	[0, 1]	1
Probability of Detection (POD) or Hit Rate	Discrimination	$\frac{a}{a+c}$	[0, 1]	1
False Alarm Ratio (FAR)	Reliability and Resolution	$\frac{b}{a+b}$	[0, 1]	0
Bias (B)	Accuracy	$\frac{a+b}{a+c}$	[0, + ∞]	1

Equitable Threat Score (ETS) or Gilbert Skill Score	Skill	$\frac{a - \frac{(a+b)(}{n}}{a+b+c-\frac{(a+}{}}$	[0, + ∞]	1

4.7.2 Comparison with real-time forecasting observation network.

The developed model can be further improved for real-time forecasting with the established real-time forecasting network. Buttal and Passara stations lies in the domain. An initial study was carried out from 25th October 2021 to 31st October 2021 to evaluate model performance for a recent heavy rainfall event. Figure 5 shows the variation of spatial averaged rainfall from the model in comparison to real-time observation station in Buttala. All the combinations could capture the peak precipitation on 26th October accurately. Further studies can be carried out to improve the real-time forecasting capabilities of the model.

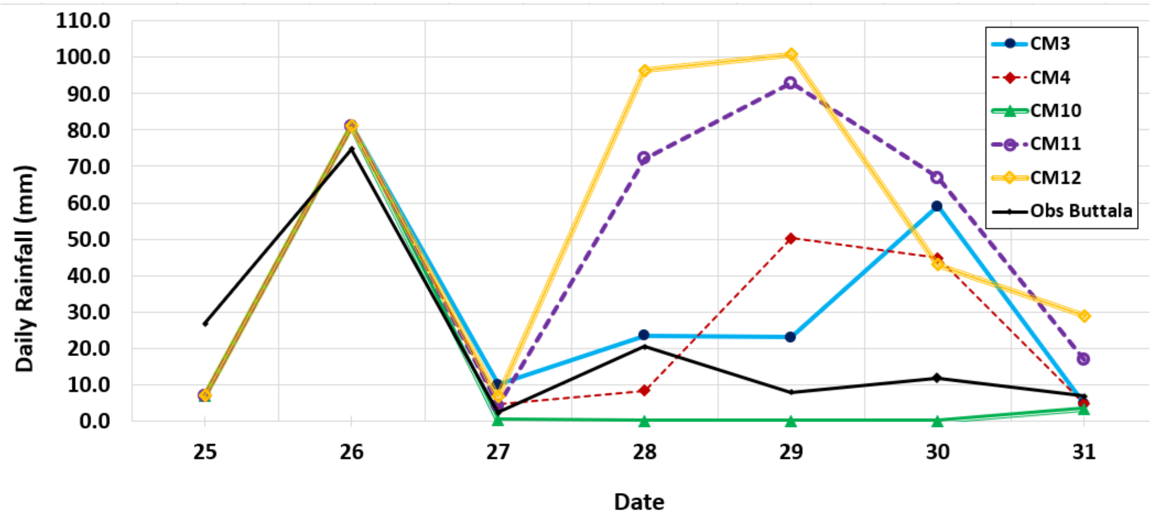


Figure 4.5 Comparison of best 5 physics combinations with Buttala real-time rain gauge station

4.8 Discussion and conclusions

Simulations of heavy rainfall events relevant to the North-East monsoon season over the Badulu Oya catchment with the different parameterization schemes exhibited significant sensitivity for both microphysics and cumulus schemes, but higher sensitivity for cumulus schemes than microphysics.

CM3, CM4, CM10, CM11 & CM12 model configurations with the WSM5, WSM6, Kessler, WDM6 & WSM6 microphysics schemes, along with the KF, BMJ & MKF cumulus parameterization schemes showed the overall best performances for the tested heavy rainfall cases of December, 2020 during the North- East monsoon season. Therefore, these model combinations have potential for operational use for numerical weather prediction over the Badulu Oya catchment.

The developed five model combinations showed acceptable predictability for the tested cases in both December, 2018 month & December, 2020 month within the North- East monsoon season. The tested model outputs displayed high sensitivity with seasonal and physical parameterization effects due to their unique methods for resolving weather features at different scales.

The comparison with real-time observation station showed capabilities of model to simulate heavy precipitation. Further studies can carry out to improve the model performance and to establish real-time forecasting system using the real-time observation network

To conclude, the filtered five model combinations can be used to predict the future large rainfall events for the Badulu Oya catchment within the North-East monsoon season and those data can be used to deliver the early warnings for the landslides within the study area.

Appendix 5 Flood in Thailand and Health Issues

5.1 Introduction

Flooding is the most common and widely observed natural disaster often resulting damage to properties, facilities and services, infrastructure, housing and structures, food and crop production, disrupting businesses and income and daily livelihood, and in worst cases injuries and loss of life. Consequences of a flood could have much broader impacts and in cases disrupting global supply chains e.g., the 2011 Thailand floods [1]. Depend on number of natural factors, a flood could be a rapid one or prolonged one but in either case they often affect directly or indirectly on people health. Floods can increase the chance of exposures to physical, chemical, and biological hazards and harmful elements in the air, water, soil, food, adversely affecting human health [2]. Three main issues are identified as consequences of a flood disaster; 1) medical and physical health (i.e., changes in fitness and activities, allergies, exposure to waterborne sickness); 2) mental health (stress, depression, sense of loss, strains on social relationships, substances abuse, or post-traumatic stress); and 3) community health (may increase interpersonal aggression, violence and crime, social instability, or decrease community cohesion) [3].

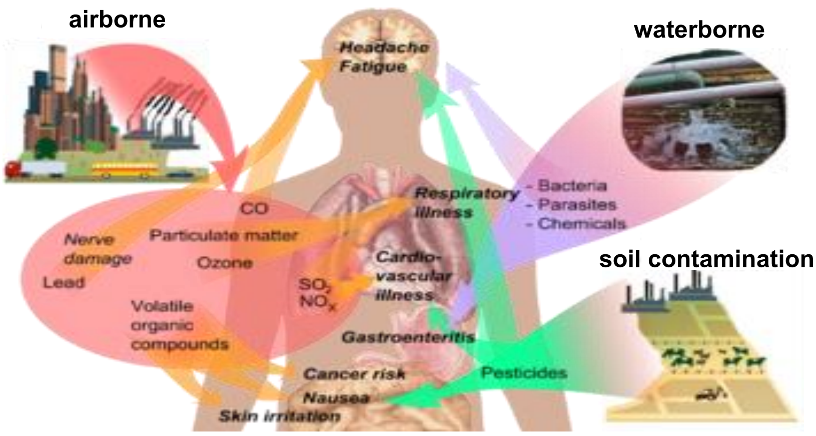


Figure 5.1 Diseases affecting on health

Image Source: https://commons.wikimedia.org/wiki/File:Health_effects_of_pollution.png

In general, during rainy season with the changes in weather also could cause illnesses such as infections in upper respiratory tract [4] while cold and flu virus outbreaks may be spread from one person to another. These could further aggravate during a flood disaster due to the limited control over hygiene. One of the other unseen and concealed health issues is the impact on mental well-being, specifically long spell of inundation easily could lead to increase of outbreaks.

Water-related diseases are also often found during flooding, i.e., diarrheal disease outbreaks and leptospirosis [5]. Standing water can act as breeding sites for mosquitoes, and therefore it is possible to enhance the risk of mosquito-borne and potential for exposure of Aedes albopictus mosquito which carry diseases like dengue [6]. Other public health issues that are of concern are safe drinking water sanitation, sufficient food or secure shelter [7], thus a changing environment caused by flood is likely to affect all of these conditions.

5.2 Types of disease during and after floods

Somjinda and Inkeaw were conducted a research on the effect of flood on elderly health in Lat Kraban District, Bangkok. Participants were age from 60 years and above and the observations found that they experienced muscle pain, athlete's foot, skin rash as well as psychological health problems during floods (i.e., insomnia, stress and tension, attention deficit, and discontentment) [8]. Number of other researchers conducted on skin diseases during floods in Thailand found that eczema, often have allergies or asthma along with itchy, red skin, was the most common skin problem. Specially, the high humidity, contaminated water, and unhygienic environment in Thailand might have increased the prevalence of bacterial colonization on eczematous macerated skin [9]. The Ministry of Public Health (MoPH) released "The People guide for prevention of communicable diseases caused by floods" [10] and listed types of disease caused by floods as follows.

- Skin infection caused by bacterial and fungal after flooding. Particularly, warm humid climates which be a perfect condition for fungi. The risk of infection is increased with traumatic injury to the skin also in people with certain underlying conditions such as diabetes, immune suppression causes of superficial infection after a flooding event [11].
- Eyes infection i.e., Conjunctivitis (pink eye) caused by bacteria in water with symptoms include a red colored eye, eye pain, burning and tearing [12].
- Respiratory infections exposure to flood waters and rain. For example, cold, flu, pneumonia which may be contracted by breathing in, or contact with, infected drops of

mucus, saliva or phlegm [12]. Respiratory diseases are often contracted by being physically exhausted around crowded areas. Typical symptoms include fever, headache, cough and fatigue.

- Hand, foot, and mouth disease usually attack children younger than 5 years old because their immunity is weaker than that of older children and adults. The virus can be transmitted through direct contact with body fluid from nose and throat such as saliva as well as fluid from blisters and the feces of infected people. Transmission can also happen indirectly through contact with contaminated toys and objects, the contaminated hands of parents or child minders, and contaminated food and drinking water [13].
- Cholera, Phattharapornjaroen, reported case of the male patient who got cholera in Bangkok floods, 2011. Cholera is an infectious disease that causes severe watery diarrhea with the symptom of nausea, vomiting, and diarrhea and his conditions were hypertension, and impaired fasting glucose. Patient ate leftover free food which was distributed [14].
- Leptospirosis, a variety of animals can spread leptospirosis, including rodents, dogs, livestock, and wildlife. During heavy rain, animal urine in the soil, stream, or water sources can be contaminated [15].
- Others, e.g., dengue fever, diarrhea, measles, heart attacks or other acute outcomes related to high stress and exertion during floods. suffering increased mental health stress and negative health effects linked with overcrowding [16]. Figure 5.2 shows distribution of cases found in 2011 affected by leptospirosis and dengue fever.

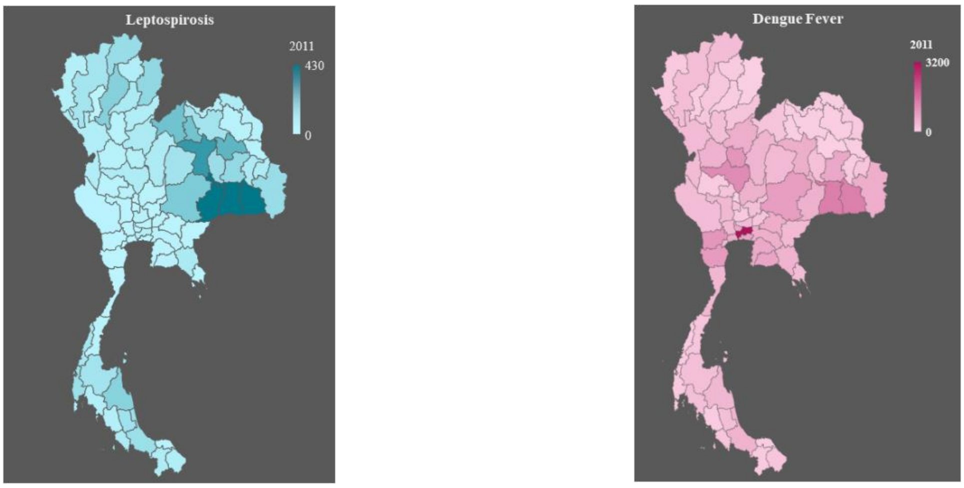


Figure 5.2 distribution of leptospirosis (left) and dengue fever (right) cases in 2011

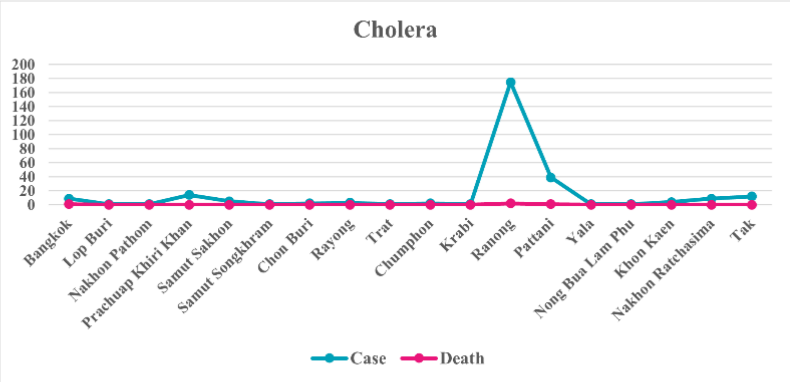
Data Source: Department of Disease Control

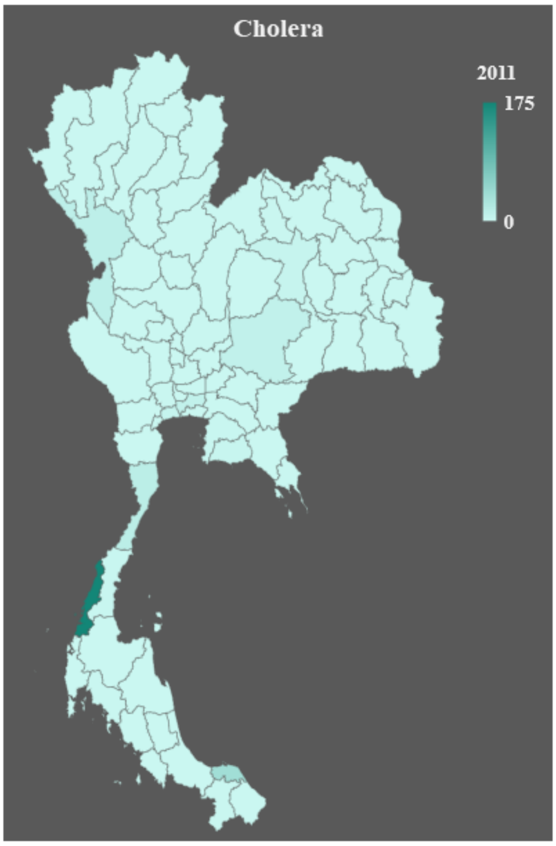
5.3 Vulnerability and accessible to medical services

Flooding has an impact on the accessibility to health and medical services; damage to property and medical equipment; evacuate patients if necessary; damage to existing medicine and supplies or new supplies are far-reaching or delayed due to weather conditions. While flooding and natural disasters threat not only the onset of events, to anyone, at any time, there are specific groups of vulnerable people that can be more at risk [17].

Vulnerability defined as the decreased ability of an individual or group to anticipate, resilience and recover from the impact of a hazard i.e., infant, young, elderly, poor, unhealthy or disability and/or uneducated people. Specifically, the elderly would suffer during disasters. Many of them may have chronic disease or physical difficulties (seeing, hearing, walking, or even sleeping). Other than that, requesting them to evacuate to shelters or relocate to safe places may be incorporated. Based on the research' results, most elderly decided not to relocate thinking they could still live at home, but they were concerned about the safety of their property [17] or may feel insecure or would rather stay familiarity of their home and neighborhoods even they may at-risk [18].

Living alone or together with elderly couples are also concerned, they may lack of support from relatives or may not connect to media or social network. Bangkok Posts news reported on November 9, 2017 that patients at Bang Saphan Hospital were forced to evacuate after heavy rains for more than 10 hours, causing floodwater in several districts. Four intensive care unit (ICU) patients with life support were transferred from the hospital to other hospital with three others waiting for relocation. Not severe patients were discharged from the hospital. Medical equipment was also moved to higher ground [19]. Figure 5.3 shows numbers of patients affected by Cholera in total 281 cases and 4 reported death. Figure 5.4 shows map distribution of patients affected by Acute Diarrhea entire country and total cases and death were 43,572 and 55 cases respectively. Based on the reported, 25 cases elderly aged over 65 years old at death which is approximately 50% of total death cases.





Province	Case	Death
Bangkok	9	1
Lop Buri	1	0
Nakhon Pathom	1	0
Prachuap Khiri Khan	14	0
Samut Sakhon	5	0
Samut Songkhram	1	0
Chon Buri	2	0
Rayong	3	0
Trat	1	0
Chumphon	2	0
Krabi	1	0
Ranong	175	2
Pattani	39	1
Yala	1	0
Nong Bua Lam Phu	1	0
Khon Kaen	4	0
Nakhon Ratchasima	9	0
Tak	12	0
Total	**281**	**4**

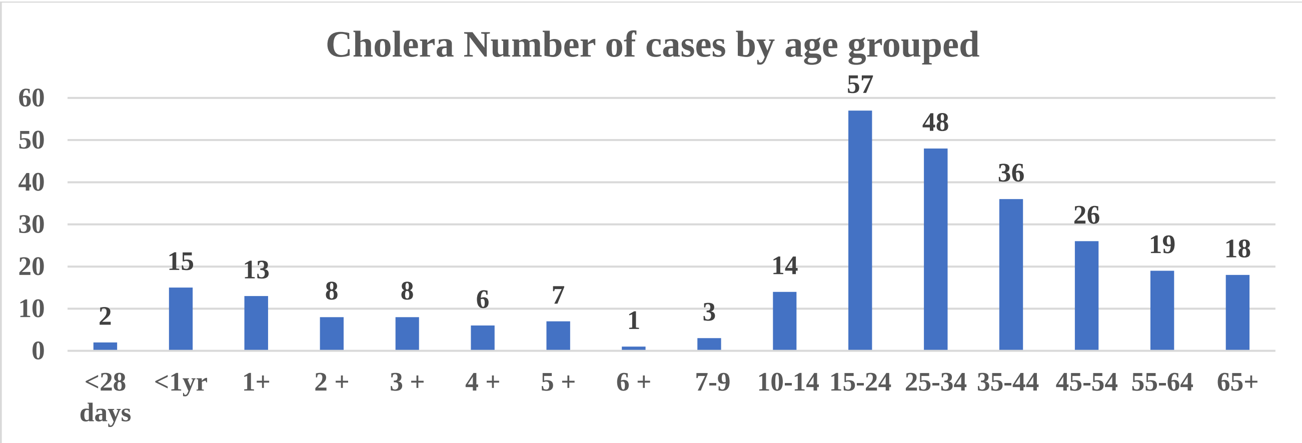
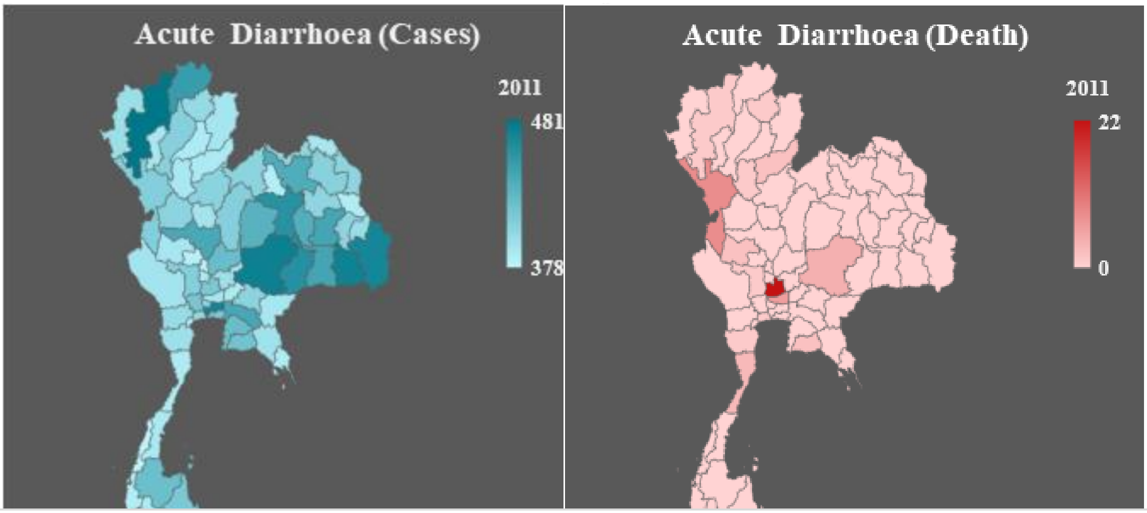
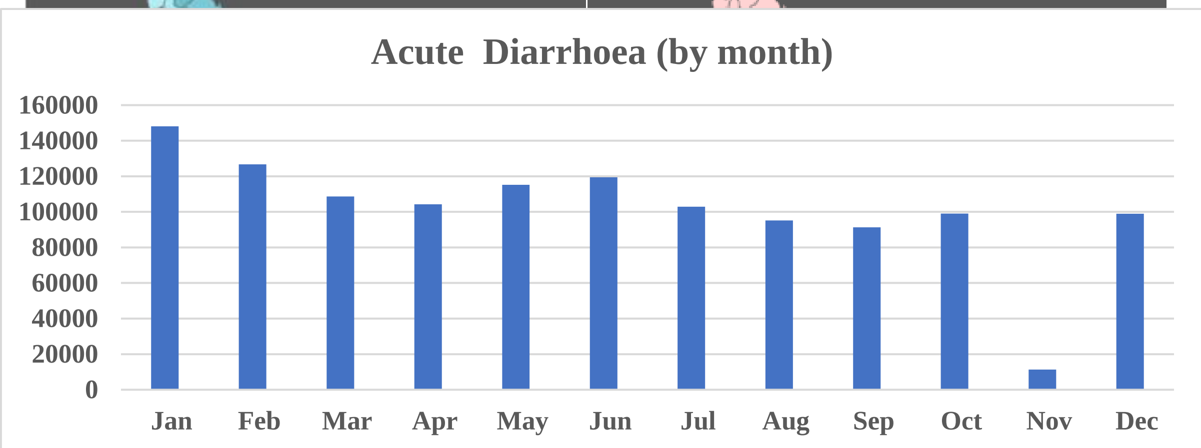


Figure 5.3 Cholera (2011)

Data Source: Department of Disease Control, http://www.boe.moph.go.th/boedb/surdata/





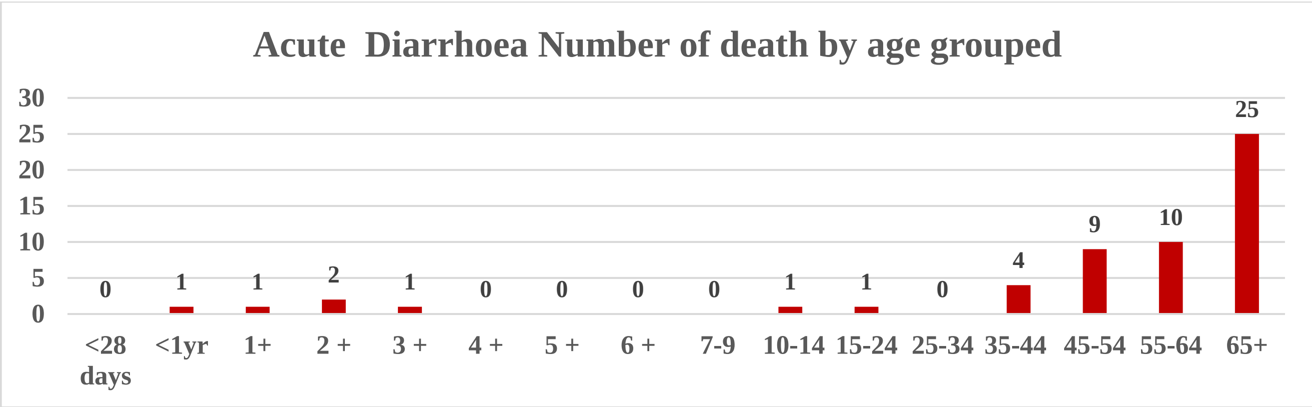


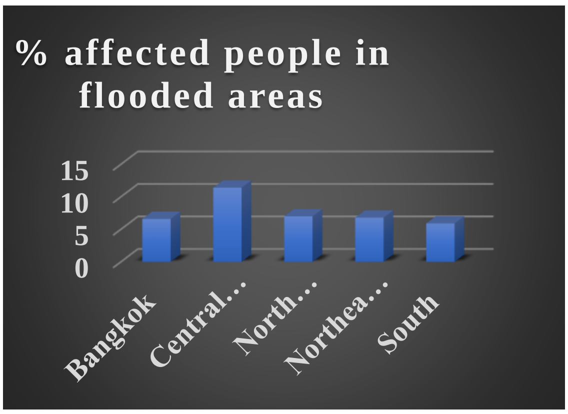
Figure 5.4 Acute diarrhoea (2011)

Data Source: Department of Disease Control, http://www.boe.moph.go.th/boedb/surdata/

2011 Thailand flood damage was very significant and it was spread through the country effecting from the north to central and to Bangkok, the capital of Thailand. Based on National Statistics Organization (NSO) survey data during July-December 2011 found that members in the household affected from flood 8.1% with 0.3 % cause death (Table 5.1). Table 5.2 shows percentage of accessible to health and medical services found that overall 15.3% willing to and able to access health services.

Table 5.1 A percentage of injury, sick or death held by household members in flooded areas

Injury, sick or death	Bangkok	Central(18 provinces)	North (16 provinces)	Northeastern (17 provinces)	South(9 provinces)	Total
Not affected	93.4	88.6	93.0	93.2	94.1	**91.9**
Affected	6.6	11.4	7.0	6.8	5.9	**8.1**
- Stress/ diarrhea/ athlete's Foot/skin	4.9	10.8	6.5	6.6	5.7	**7.5**
- injury	1.5	0.8	0.4	0.1	0.2	**0.6**
- death (electric shock, chronic disease, etc)	0.3	0.2	0.3	0.2	0.2	**0.3**



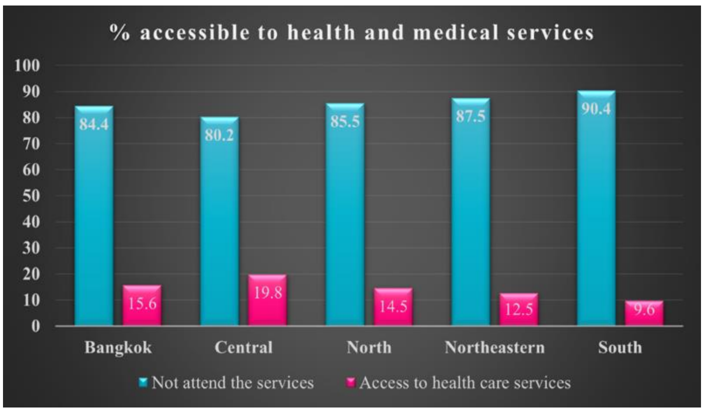


Table 5.2 A percentage of accessible to health and medical services

Health and medical	Bangkok	Central	North	Northeastern	South	Total
Not attend the services	84.4	80.2	85.5	87.5	90.4	**84.7**
Access to health care services	15.6	19.8	14.5	12.5	9.6	**15.3**
- Normal	9.2	13.1	10.0	8.0	8.4	**10.2**
- Mobile medical unit	2.3	5.0	4.2	4.3	0.7	**3.9**
- could not access the services as	4.1	1.7	0.3	0.2	05	**1.2**

5.4 Thailand river system

Previously, Thailand had 25 river main basins with 254 sub-basins [20]. In June 2018, the government had established the Office of the National Water Resources (ONWR) as the main organization to control water management policy and revised the river system of Thailand into 22 river basins [21]. Figure 5.5 shows 22 main basins of Thailand.

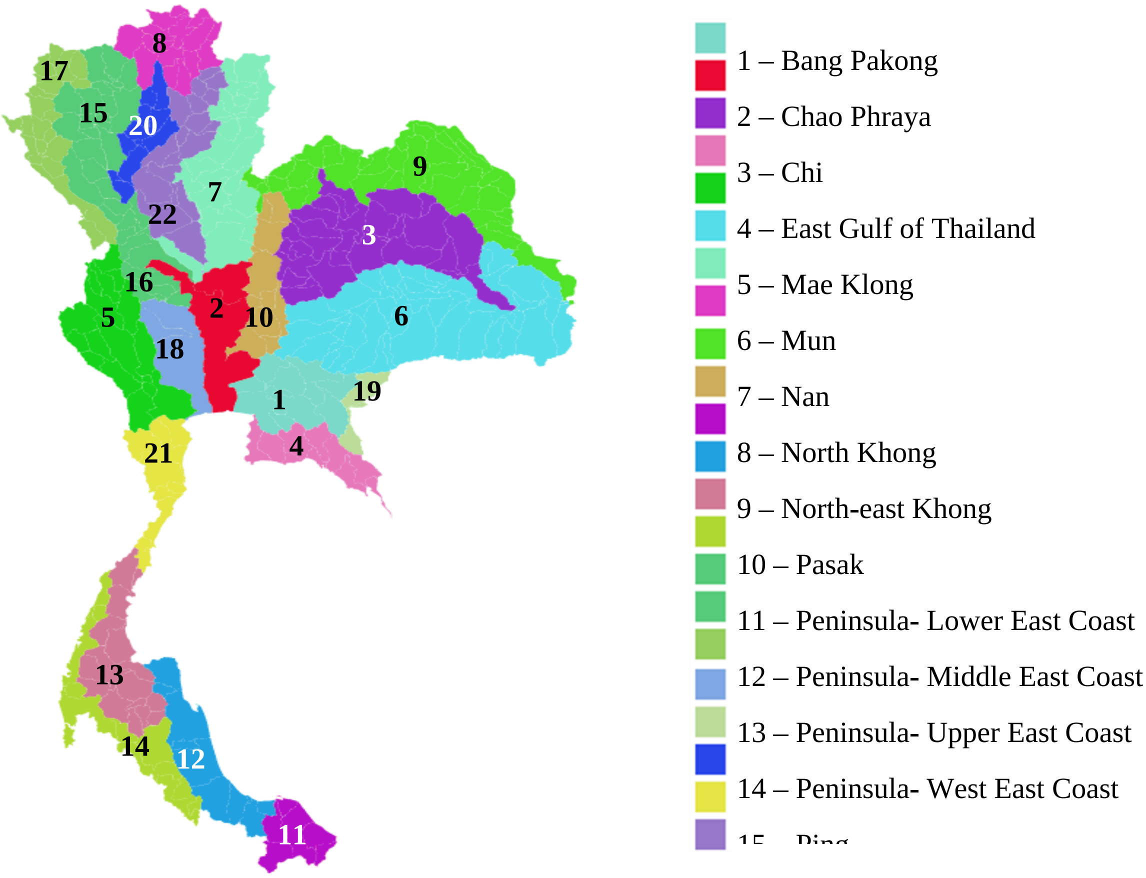


Figure 5.5 Thailand 22 river basins

Chao Phraya is the principal river systems of Thailand covers 11 provinces (Nakhon Sawan, Chainat, Singburi, Lopburi, Pathumthani, Nonthaburi, Samutprakan, and Bangkok) with 2-sub-basins; (1) Bung Boraphet covers approximately 4,390 sq.km.; and (2) Chao Phraya plain covers approximately 15,880 sq.km. The Chao Phraya River begins at the confluence of the Ping and Nan Rivers at Nakhon Sawan province. It then flows from north to south approximately 370 km. from the central plains through Bangkok to the Gulf of Thailand (Figure 5.6). Water from these resources supports consumption sectors e.g., community water and sanitation services, agriculture irrigation, and manufacturing industry.

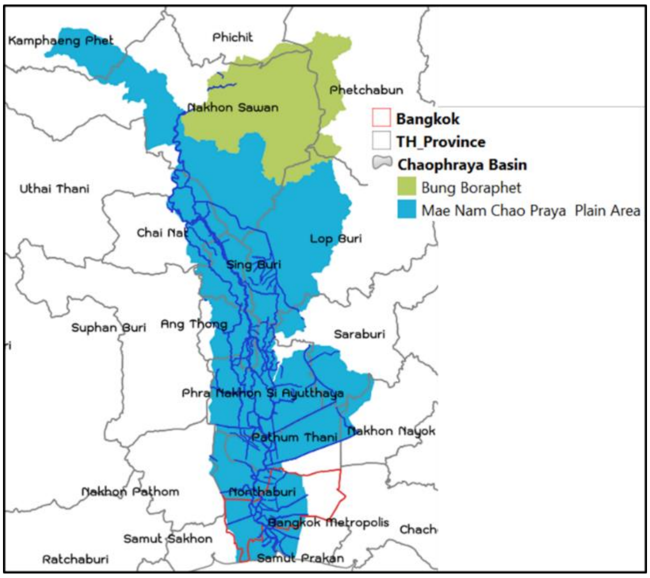


Figure 5.6 Chaophraya 2 sub-basins

5.5 Flood situations in Thailand

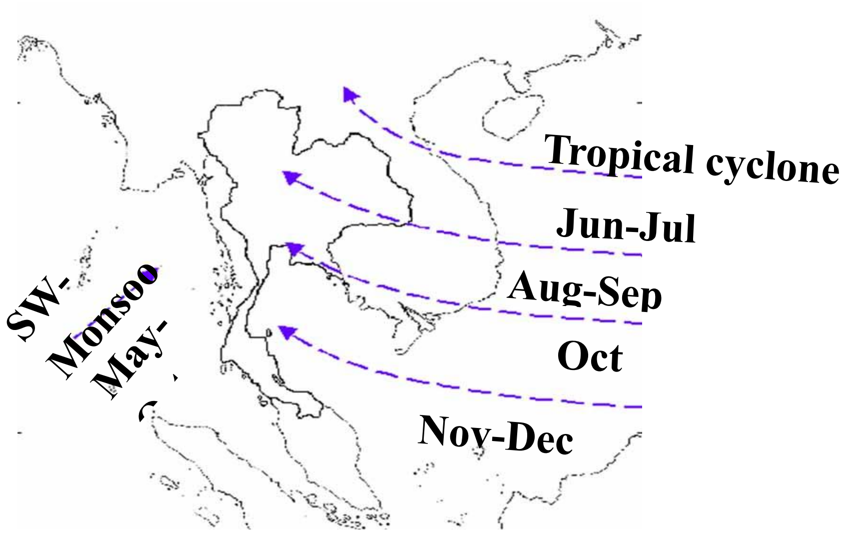


Figure 5.7 Monsoon (Modified map from the Thai Meteorological Department)

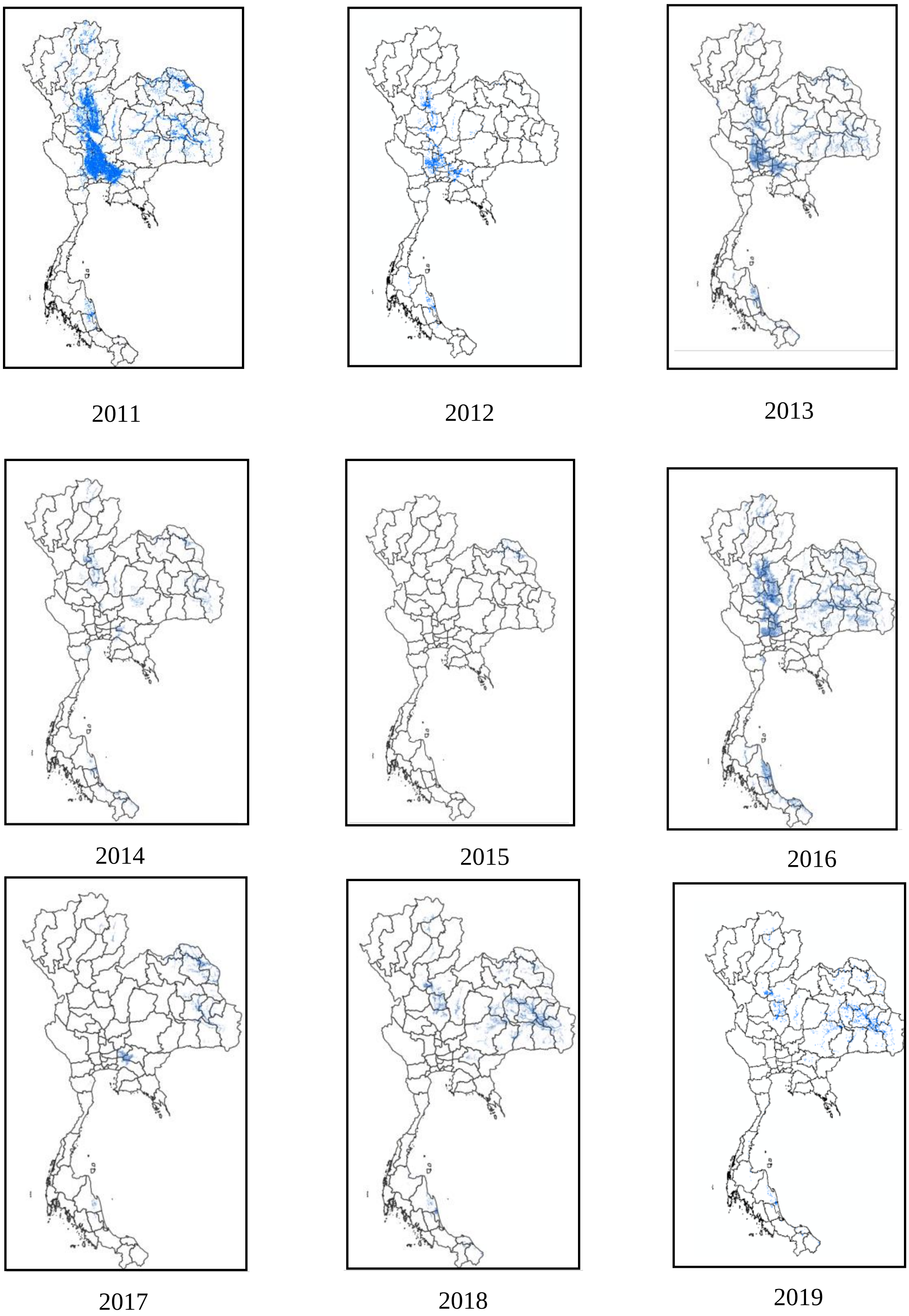


Figure 5.8 flooded area in 2011-2019 (Data source: GISTDA)

Thailand is a flood prone area, recently amount of torrential rain often increase and severe in differing degrees of the storms, posing immediate and long-term challenges for all Thais. Thailand floods occur annually during monsoon season which lasts from late April to early November in different regions (north to south). Figure 5.7 shows monsoon direction in each period. A monsoon is traditionally a changing weather corresponding with wind and precipitation. As normal flood effects, inundated areas in rural or urban, and industrial zones caused damages surroundings and changing living activities and health problems (food poisoning, athlete's foot, dengue, malaria, etc.) and accidents (drowning, poisonous animals or electric shock). Figure 5.8 shows flooded area in 2011-2019 (Data source: GISTDA

5.6 Flood case study in Hua Wiang Municipality, Phra Nakhon Si Ayutthaya (Ayutthaya), Thailand

This research study was a part of a special problem program, Geography Department, Kasetsart University [22]. Two main purposes were 1) to find repeated flooded areas using Landsat imageries in year 2009, 2010, 2011, 2013, 2016 and 2017; and 2) to find community affected by flooded. Hua Wiang Municipality, Sena District, Ayutthaya covered area 22.25 sq.km. with 2 sub-districts (Ban Kratum and Hua Wiang) and 23 villages.

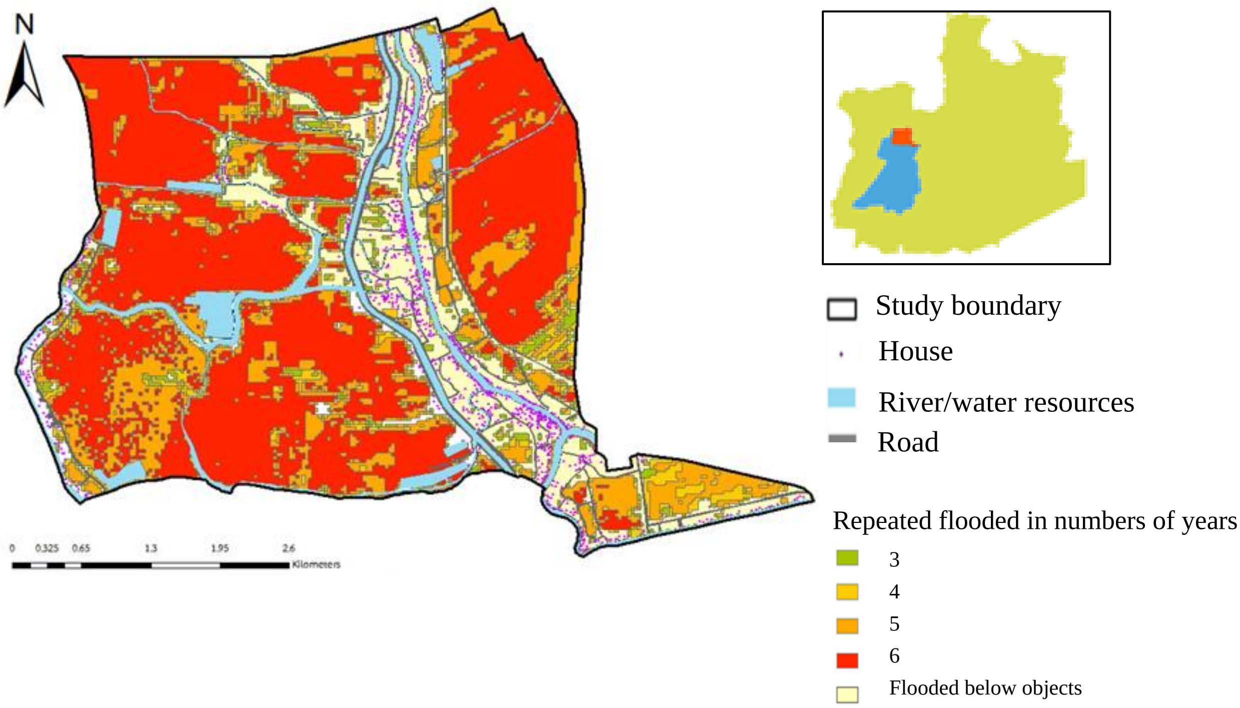


Figure 5.9 repeated flooded in Hua Wiang Municipality, Ayutthaya

Based on questionnaire housing material affected at high level due to houses made by wood. However, housing characteristics affected at low level because most of houses raised off the ground due to people aware of frequently flood occurs in the areas. Community flood preparedness found at moderate level. Consequences of income effect found at low level affected due to most of people in Hua Wiang are housewives. Workers still communicate to their work places but situation effects the commuting time to works.

5.7 Proposed and to be continued research on "Cloud-based Google Earth Engine (GEE) of Inundated area mapping, and effects on surface water quality and human health"

Thailand is a flood prone country with many vulnerable areas for floods occurring almost every year. Many researchers have found that communicable diseases such as cholera, diarrhea, skin diseases etc. have significant impact on human health and often lead to serious illnesses or in some cases to death.

It is suggested to investigate the factors that are related to waterborne diseases discussed above and identify possible relationship both on the prevalence and spatial distribution in an orderly manner reaching out for scientific analysis and results to support the safety of communities. Thus, the following activities could be considered to follow up with this survey based on literature;

- Identify inundated areas using GEE;
- Monitor surface water quality based on key indicators of flood and non-flood areas; and
- Spatial temporal analysis to establish relationship of common water indicators on the health of the flood affected societies.
- Identify possible counter measures to improve human health during a flood situation.

The water quality data could be acquired from related organization such as Thailand Pollution Control Department (PCD), Department of Disease Control (DDC) and field samples data collection in areas where important data are missing.

Appendix 6 Training program on SWMM

6.1 Introduction

Stormwater management is the effort to reduce runoff of rainwater or melted snow into streets, lawns and other sites and the improvement of water quality, according to the United States Environmental Protection Agency (EPA). Without proper stormwater management, infiltration can decrease reducing soil replenishment and groundwater recharge. It is worth noting that soil moisture is essential in sustaining vegetation and the reason it has a role to play in maintaining the natural hydrologic cycle.

6.2 Objective

The objective of the program is to provide training on the use of the Storm Water Management Model (SWMM) of Environmental Protection Agency (EPA) of USA. The target group is postgraduate students working on urban water management and water quality modeling. The training covers introducing concepts and hands on training on modeling urban storm water drainage, water quality modeling, assessing impacts on nature-based solutions on the quantity and quality of storm water drainage and assessing storm water management project proposal utilizing the model using real world case studies and data.

6.3. SWMM Software

EPA's Storm Water Management Model (SWMM) is used throughout the world for planning, analysis, and design related to storm water runoff, combined and sanitary sewers, and other drainage systems. It is a Windows-based desktop program made available as open source public software and is free for use worldwide. Model can be used to design storm runoff reduction through infiltration and retention, and help to reduce discharges that cause impairment of water bodies

6.4 SWMM Course Book

The course book describes EPA Storm Water Management Model (SWMM) model which is a dynamic rainfall-runoff simulation model that computes runoff quantity and quality from primarily urban areas. This is a practical application guide for users who have already had some training in hydrology and hydraulics. It contains some of the most common types of stormwater management and design problems encountered in practice, which are used to evaluate grey infrastructure stormwater control strategies, such as pipes and storm drains, and is a useful tool for creating cost-effective green/grey hybrid stormwater control solutions. SWMM was developed to help support local, state, and national stormwater management objectives to reduce runoff through infiltration and retention, and help to reduce discharges that cause impairment of water bodies.

6.5 SWMM Course Delivery

All lectures were conducted via Zoom. Initially, the participants were given an agenda or plan for each lecture by Screen Sharing a document or slide at the beginning of lecture. This gives students a clear idea of how the class will progress, what will be covered, and the activities they'll engage in.

Figure 6.1 Zoom Class

Assignments were submitted through mails and can directly uploaded into a web. All the lecture notes, ppt's and the other relevant documents can share through the web (Enviforcasting). It can set up automatic email notifications to inform all the participants about certain events, such as:

- The expiration of a subscription.
- The suspension of an account.
- The resource usage limit for a subscription being exceeded, and so on.

The notifications are customizable. For each notification can specify its recipients, Change its text and subject, Customize its look and See how it looks in emails which is very effective way to communicate with the persons. The platform has all the essential tools need to support efficient teaching and learning. Also supported face-to-face learning, and online and blended learning solutions which facilitate and improve upon traditional educational methods. It can also save organizations time and money by allowing the easy administration of large amounts of information in a user friendly, web based environment.

6.6 Component Description

This program consists of three components, the first two were teaching components and the third one is a review/feedback program.

- Hydrodynamic modeling (3 classes)
- Water Quality modeling and measures for water quality improvements (4 classes)
- Review and discussion (2 classes)

6.7. Reading Materials

All students were advised to installed the SWMM software *(Version SWMM 5.1.015)* downloaded from the EPA site:

https://www.epa.gov/water-research/storm-water-management-model-swmm

Self-Extracting Installation Program for SWMM 5.1.015 (EXE)(32 MB)

Also, downloaded the SWMM 5.1 User's Manual and Reference manuals from the same website.

Location and the period of the workshop: The classes were delivered in Kandy, Sri Lanka, and students in Beijing, China, from 18:30 to 20:30 (Beijing time), which is 16:00 hrs to 18 hrs in Sri Lanka and 19:30 to 21:30 in Japan, from October 30th to November 12th, 2021.

6.8 Training program Schedule

Dr. Srikantha Herath from Enviforecasting opened the workshop. He welcomed all the participants and indicated the main objective and the students' final outcome during this training period.

Then the Workshop Programme and schedule of activities accomplished were summarized as below from the period of Oct 30th – Nov 12th, 2021

Date	Content Covered
30th October, 2021	• Introductory lecture on storm water drainage • Introduction to SWMM modelling approach for catchment runoff generation following a storm, routing of flow along storm drainage network. Introducing SWMM Reference Manual Vol. I and Vol. II Hydrology and Hydraulics • Installation of the SWMM modelling software and introducing the use of SWMM Reference Manual • Demonstration of SWMM application potential using a Case study already carried out for an urban storm water drainage development project in an urban are of Sri Lanka
1st November, 2021	• Hands on guidance to set up the model for an area using the Tutorial activity demonstration. Setting up of catchment hydrologic parameters, drainage network and its hydraulic parameters properties using the interactive tools provide by the SWMM software (Ref, EPA SWMM User's Manual Version 5.1) • Participants were guided to gain experience in model setting up and confidence in running the model, and familiarizing presentation and interpretation of model generated results using display and reporting tools provided by the SWMM software. • Running of SWMM Model together with participants for an already set up Case study of SWMM application for Sainthamaruthu area in Sri Lanka to demonstrate the selection of design storm, design of runoff collection /junctions, canal/pipe networks, outfall etc. • Participants were given an assignments to carry out analysis and design of a storm water drainage system for a design storms of a selected area using SWMM
5th November, 2021	• Presentations by the participants on the developed design in their selected area. Discussion class to clarify the questions and issues cropped up during the model application for analysis runoff and sizing of conveyance elements of the network

	• Explanation on the format/template of the Case study report: Part I Hydrologic and Hydraulic Analysis and design of drainage network, results interpretation
9th November, 2021	• Introductory lecture on catchment pollutant generation, storm water quality modelling • Introduction to SWMM modelling approach for pollutant generation following a storm, routing pollutants with of flow along storm drainage network. Introducing SWMM Reference Manual Vol.III Water Quality and representative concentrations of pollutants • Tutorial activity demonstration based on Chapter 2 in EPA SWMM User's Reference Manual Version 5.1
10th November, 2021	• Introduction of LIDs and explanations on LIDs introduction in SWMM for the runoff regulation and water quality improvement (SWMM Reference Manual Vol. III) • Running of SWMM Model for water quality parameters together with participants for an already set up Case study of SWMM application for Sainthamaruthu area in Sri Lanka to demonstrate introduction of control parameters for water quality modeling and model applications together with interpretation of results using SWMM tools • Case study of deployment of LIDs and impact of LIDs • Participants were given an assignments to carry out analysis of water quality for a design storms of their selected area using SWMM. Also, to introduce LIDs in their area and investigate the impact LIDs on runoff regulation and water quality improvement
12th November, 2021	• Presentations by the participants on the water quality modelling applied to selected pollutant concentrations in their selected area. Discussion class to clarify the questions and issues cropped up during the model application for analysis concentrations and introduction of LIDs. • Guidance for application of SWMM, selection of water quality parameters based on data availability, and the potential use of water

	SWMM quality modelling in urban storm water quality management interventions • Explanation on the format/template of the Case study report: Part II Water Quality Analysis and deployment of LIDs, results interpretation
Date:	• Review after submission of the Case Study Project Reports by individual student

6.9 Tasks assigned for the students

During the course students were given assignments covering different phases of the course and present results. The questions students had were summarized in to groups and a group representative presented them to the resource persons to clarify areas students had difficulty in following up. The participants were requested to make a review report on water quality Case Study Project by individual student as a final assignment. All communications were carried out through the coursework module customized for this course.

The course work module makes automatic email messages to all participants of new posts, distribute the reading materials and also was used to make available relevant resources such as course texts, manuals, tutorials and recordings of the lectures.

The Figure 1 shows a snap shot of the course work group interface and Figure 2 and Figure 3 shows interface for student interaction and submission of assignments.

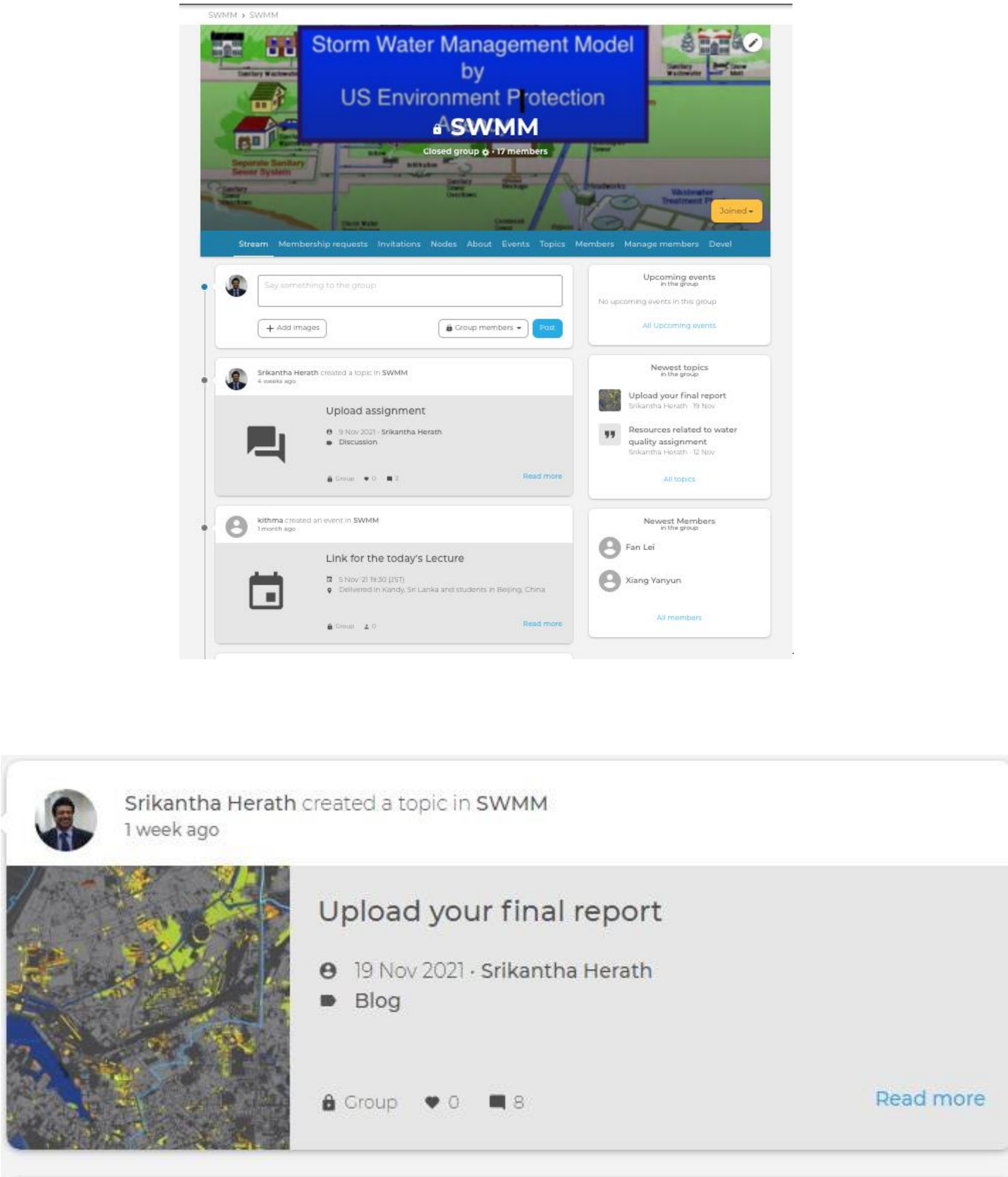


Figure 6.2 Interface for Submitting Final Assignment