ASIA-PACIFIC NETWORK FOR GLOBAL CHANGE RESEARCH

ARCP Final Report

Project Reference Number: ARCP2015-11CMY-Mishra

Climate Change Adaptation through Optimal Storm water Capture Measures: Towards a New Paradigm for Urban Water Security

The following collaborators worked on this project:

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Institute for the Advanced Study of Sustainability

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1.

Project Overview

Project Duration	:	2 years
Funding Awarded	:	US$ 35,000 for Year 1; US$ 30,000 for Year 2
Key organizations involved	:	Dr. Binaya Kumar Mishra, Mr. Chitresh Saraswat, Mr. Abee Mansoor, Ms. Anjana Dahal, United Nations University - Institute for the Advanced Study of Sustainability, Tokyo, Japan; Dr. Sutat Weesakul, Dr. Winai Chaowiwat, Mr. Dechphol Chitwatkulsiri, Asian Institute of Technology, Bangkok, Thailand; Dr. Tran Thuc, Dr. Mai Van Khiem, Mr. Luu Linh, Institute of Meteorology, Hydrology and Environment, Vietnam

Project Summary

Water management became challenging and expensive in the global change context (climate change, urbanization). The major shortcomings of existing research on water management systems are: the neglect of uncertainty in climate change, inadequate knowledge about the infrastructural response sensitivity and nonlinearity in probability propagation from climatic to socio-economic loss, and the lack of a holistic water management framework and most important is the lack of consideration of local aspects in formulation of adaptation strategies. The goal of this project was to develop methodologies for local governments and the local community for adapting to climate change by preserving local water cycle using water sensitive urban infrastructure development. Considering the hydrologic and social point of view, this research attempted to address the challenges of extensive urban floods due to increasing of extreme rainfall intensities in the wet season. Impact of climate change was investigated by considering precipitation projections of various GCMs (Global Climate Models) over Bangkok, Hanoi and Tokyo study area. The study proposes maintaining the stability of the water cycle of the urban catchment as an alternative for sustainable water management.

Keywords: Stormwater runoff, climate change adaptation, water management, sustainable urban development

Project outputs and outcomes

Outputs	Outcomes
<u>Estimates of likely changes in future extreme rainfall pattern</u> under climate	Improved data and capacity of hydro-metrological analysis in study area

change scenarios for hydrological analysis in study areas (a representative basin inside Tokyo, Bangkok and Hanoi)	
Identification of the feasible sustainable water management measures for the preservation of local water cycle	Improved understanding of water management in study area
Household survey review reports on understanding of local's perception of alternative infiltration and storage facilities.	Increased awareness in study area on alternative stormwater capture measures
Identification of key factors and processes that are important to the flood and groundwater recharge as well as strategies and measures to increase urban water security	Improved understanding in form of published paper of key factors and process to increase urban water security
Development of methodologies internationally, to advance active learning among both stakeholders and students through the networks of higher education	Improved knowledge on the importance and use of alternative stormwater capture measures through active learning among students and stakeholders

Key facts/figures

(1) Used multiple (2-5) GCMs output in assessment of climate change impact assessment to minimize large uncertainty in climate projections
(2) An increase of 5 to 50% in future extreme rainfall intensities for different return periods (2 to 100-years) and GCMs
(3) 33 persons from various water fields were involved in a discussion on the alternative stormwater capture measures
(4) Trained 7 Master students for analyzing climate change impact on precipitation extremes and stormwater

Potential for further work

Given a large uncertainty existed on projected rainfall intensity of different climate models, developing an ensemble model could be proper solutions to diminish this uncertainty. This work can be extended towards a holistic research on stormwater management. This research can also be extended to manage science-policy interface in efficient way.

Publications

Rehan, M., Weesakul, S. and Winai C. (2017). Development of Design Storm Pattern with Climate Change in Monsoon Asia. THA 2017 International Conference on Water Management and Climate Change Towards Asia's Water-Energy-Food Nexus.

Weesakul U., Chaowiwat W., Rehan M.M. and Weesakul S. (2017) “Modification of a Design Storm Pattern for Urban Drainage Systems Considering the Impact of Climate Change”, Engineering and Applied Science Research(EASR), July-September 2017, 44(3),p 161-169.

Saraswat, C., Kumar, P., & Mishra, B. K. (2016). Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi and Tokyo, *Environmental Science & Policy*, *64*, 101-117.

Mansoor, A., Mishra, B.K. and Herath, S. (2015). Assessing impacts of climate change on rainfall extremes for sustainable stormwater management in Yato Watershed, Tokyo, International Expert Workshop ‘Towards Urban Water Security in Southeast Asia: Managing Risk of Extreme Events’, pp. 213-223

Acknowledgments

Authors would like to acknowledge various students and staff of the United Nations University, Tokyo, Japan; Asian Institute of Technology, Bangkok, Thailand; and Institute of Meteorology, Hydrology and Environment, Vietnam as well as local experts in the study cities for the collaboration and suggestions in completing the project successfully. We would also like to thank the Asia Pacific Network for Global Change Research (APN) for financially supporting this project (ARCP2014-20NMY-Mishra): Climate Change Adaptation through Optimal Stormwater Capture Measures: Towards a New Paradigm for Urban Water Security.

1. Introduction

Dealing with climate change is the most important challenge the world is facing today, posing unprecedented multidimensional challenges for all countries and communities in the Asia-Pacific region characterized by the uneven distribution of precipitation between wet season and dry season. With an energized global water cycle, the future climate is expected to have increased rainfall intensities and longer non-rainy days. Thus, increased rain intensities and prolonged water scarcity periods are two of the most pressing problems associated with climate change. Water resources will be affected by both quantity and quality, and hence water, stormwater, and wastewater facilities' infrastructure will face a greater risk of damage. The effect of the climate change will manifest from difficulties in operations to disrupted services and increased cost of the water and wastewater services. Governments, planners, and water managers have to, therefore, re-examine development processes for municipal water and wastewater services and adaptation strategies to incorporate climate change into infrastructure design, capital investment projects, service planning, and operation and maintenance. The expected climate change impacts of increased rainfall intensities, resulting an increase in direct runoff, and hence quick rise in stream flow and depletion in groundwater table are similar to urbanization impacts on the water cycle. Urbanization too leads to similar impacts on the water cycle. Increased impervious areas and construction of stormwater drainage network that shorten the time of concentration and increases direct runoff, resulting in a quick rise in stream flow and depletion of groundwater table. Therefore, experiences and methods adopted in coping with water management to urbanization can also be used for adaptation to climate change. Many developed countries, including Japan, have adopted practical measures for minimizing the impact of urbanization on water management system. However, the additional increase of future rain intensities is a major concern.

It is not appropriate to seek for large-scale investments in further flood controls, especially under the large degree of uncertainty associated with climate change. Therefore 'soft' measures such as societal inclusion, especially their cultural aspects in reducing risk are an imperative to meet the future flood control demands. The soft measures that can be adopted readily under uncertain future climate are onsite measures, in the form of storage facilities incorporated in the city planning to prolong the time of concentration together with infiltration facilities to infiltrate excess rainfall runoff from rooftops and paved areas to reduce the direct runoff volume. These onsite facilities thus recover the pre-global change infiltration and retention functions and help revert the hydrological cycle to its original state. To address urbanization through onsite measures, pavement materials, drainage components as well as storage systems have been developed to improve efficiency and effectiveness of such systems. This research proposed to have similar kind of development in relation to climate change for restoring local water cycle. This research investigated the stability of local water cycle as the target for sustainable urban stormwater management. This requires taking an integrated approach to stormwater management by understanding and managing the total hydrological cycle. Among all the problems caused and aggravated by climate change, flood and water scarcity are the critical issues in densely urbanized cities like Tokyo and rapidly growing cities like Bangkok (Thailand) and Hanoi (Vietnam) although several stormwater management programmes are being implemented/proposed in these cities. The results will help local governments to incorporate strategic decisions in response to climate change in a consistent framework and investigate technologies suited for water management from both a short- and long-term perspective.

Promotion of rainwater storage and infiltration facilities will much contribute to the well balanced hydrological system and the reduction of global warming impact. Computer-based modeling is utilized to assess and analyze the hazard and vulnerability, and it helps to acquire the comprehension of the magnitude and frequency of the event. Therefore, this project tried to advocate on-site measures to simulate and test adaptation strategies to reduce the varying range of climate change-induced floods and water scarcity to cope with future climate uncertainty with the basement on the current water cycle and hydrological processes in a representative Tokyo, Bangkok and Hanoi watersheds. Countermeasures of urbanization, drainage and storage of the excessive rainfall during the wet season can be introduced to cope with floods and at the same time to compensate the water scarcity during the dry season so as to restore water cycle into the original state. Thus, the incremental flood and water scarcity problems brought about by climate change will be addressed. That is to say, the overall objective of this study is to review and analyze various on-site measures that can help restore the water cycle to pre-climate change condition, reduce the flood and drought disaster due to future climate uncertainty.

2. Methodology

This study combined meteorological, hydrological, engineering and socioeconomic research in order to provide methodologies and a framework useful for strategic planning to address water management in urban areas under climate change and urbanization. The research combined climate change risk quantification, physical process simulation and decision making for water management planning and implementation in the urban watershed context. The research approach (Fig.1) is described below.

1. GCM outputs were analyzed and evaluated to establish the validity of the GCM simulations in the local context. GCM outputs suffer from two inherent drawbacks, namely coarse resolution and biases in their frequencies/magnitudes which warrant that GCM output should not be used directly at the local scale. The drawbacks were minimized using quantile-quantile bias correction technique (statistical downscaling).

2. Changes in the hydrological regime were analyzed using distributed hydrological model to carry out hydrological analysis and establish catchment scale water cycle for the current and future climate data.

3. Performance of on-site facilities and develop optimum adaptation strategies were analyzed using high-resolution distributed hydrological model coupled with onsite facility performance at grid level. Several simulations were carried out iteratively for different policies for onsite facility installations until the hydrological cycle is close to water cycle prior to climate change.

4. Previous reports on local perception on alternative infiltration and storage facilities were reviewed to understand locals' cultural values and perception and their willingness to install the infiltration facilities in reducing urban flood risk and improving urban water balance. This way local view on flood risk and the understanding of the implications and limitations of urban stormwater management measures were analyzed.

5. Finally, research findings were disseminated to various professionals and academicians on the importance of alternative stormwater capture measures to help address the problem of urban water security. Dissemination of research findings was carried out by (i)

interactive communication through expert meetings (ii) organizing stakeholder forum meetings and seminars with different sectors to share various outcomes of the project and (iii) publications in peer-reviewed journals and conference proceedings.

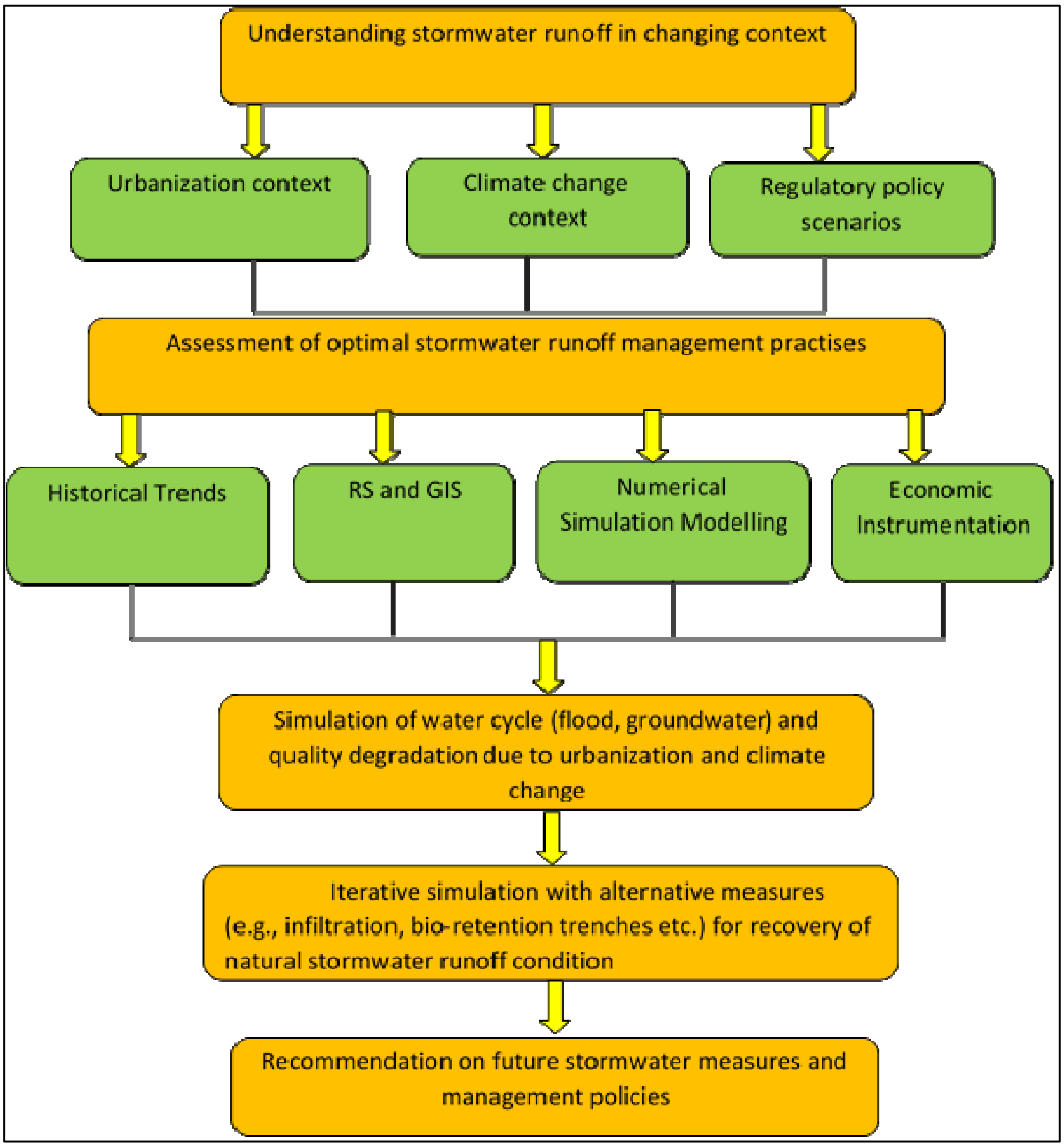

Fig. 1 - Research Methodology

3. Results and Discussions

The project progressed as decided during the inception workshop, with the goal of (1) estimating likely changes in future rainfall/temperature pattern under climate change scenarios in three cities: Tokyo, Bangkok and Hanoi by (i) spatial/temporal downscaling, bias-correction, (ii) preparation of rainfall intensity-duration-frequency curves and (iii) selection of a representative catchment for flood simulation under climate change scenarios and (2) Identification of key factors and processes that are important to the flood and groundwater recharge as well as strategies and measures to increase urban water security. Some of the study results has been summarized below:

In Bangkok, Thailand case, the project achieved results with downscaling of the climate data, temporal disaggregation to hourly resolution, generation of IDF curves for present and future time periods and modeling of urban drainage (Fig. 2). Analysis of recorded rainfall was conducted in order to obtain the IDF curve using Gumbel distribution. Storm advanced coefficients (r) was derived as a function of rainfall duration. Results of "r" values with a maximum as 0.49 while the minimum as 0.20 show that they vary with storm duration. It means that design storm is almost symmetric for short duration. For longer duration, the timing of peak intensity will occur earlier but not less than 20% of rainfall duration. Recorded storm data was extracted for 2 years return period for 42 storms ranging from 35 to 585 minutes. There were 5 and 2 selected storms corresponding to 5 and 10 years return period. The CDS (Chicago Design Storm) was found to be the best fit using those three criteria when they were compared with 49 storms. The storm pattern can be observed virtually as in that CDS is better than others. Time to peak is the same for all design storms for short duration. In addition, results show that the peak intensities derived by CDS are much higher than the measured peak on the average with 53% to 57%, therefore the CDS is needed to be modified.

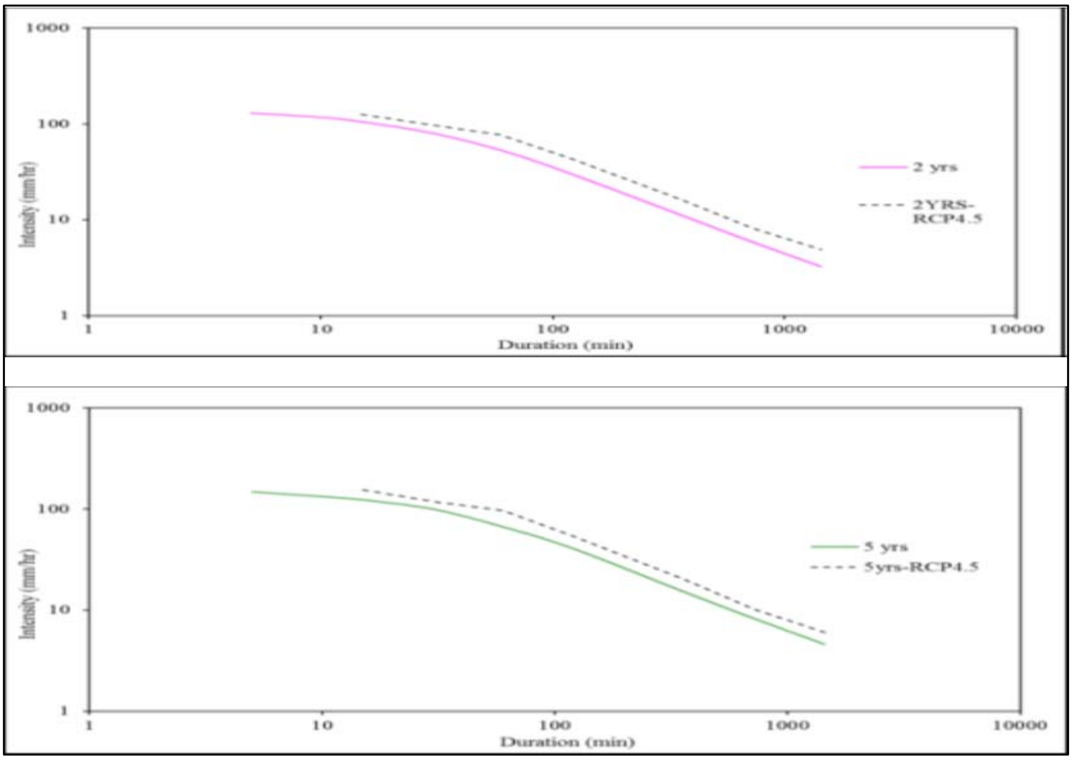

Fig. 2 - Comparison of IDF curves for present and future 2015-2039 under RCP4.5

In Tokyo, Japan case, the study was carried out at Yato watershed situated in Setagaya ward, which is the second largest ward in Tokyo. In this study, rainfall data of 30 years record length ranging from 1976-2005 at Setagaya rainfall station (location 35°37.6'N, 139°37.2'E) were collected for confirming the simple scaling properties. Rainfall intensities of 1-, 3-, 6-, 12- and 24-hour durations were tested to investigate the scaling properties as finer sub-daily rainfall was not available. A log-log plot of the moments against their durations was examined for moment order q=1, 2, 3, 4 and 5. Fig. 3 illustrates q^{th} moment of the rainfall intensities (mm/h) against different durations. With the application of the simple scale scaling model for rainfall intensities at Setagaya rainfall station, the scale factor was estimated to be 0.6012. Assuming Gumbel distribution, the rainfall IDF for sub-daily duration rainfall intensities was estimated (Fig. 4).

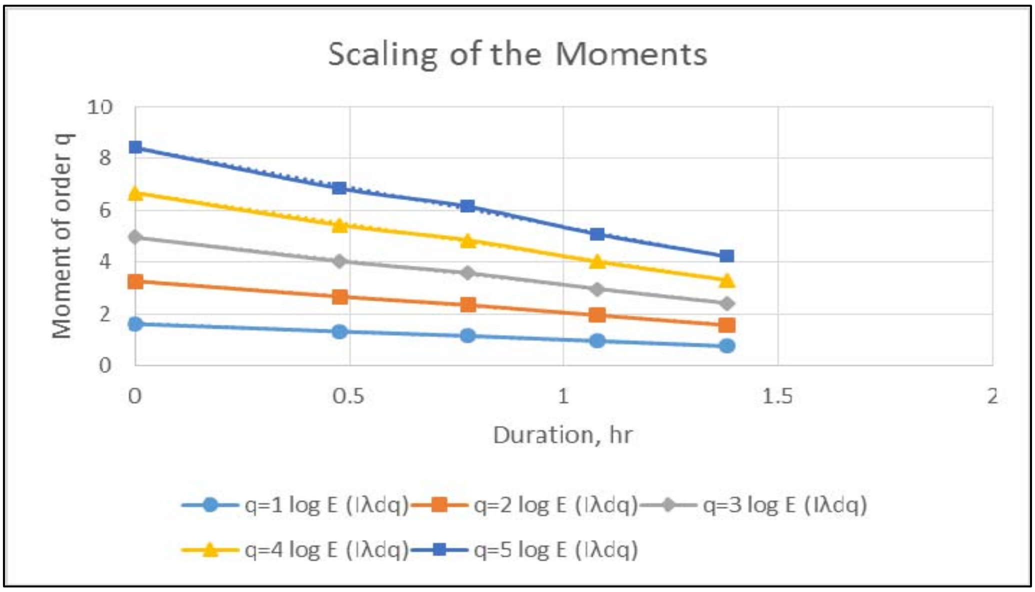

Fig. 3- Scaling of the moments at Setagaya rainfall station

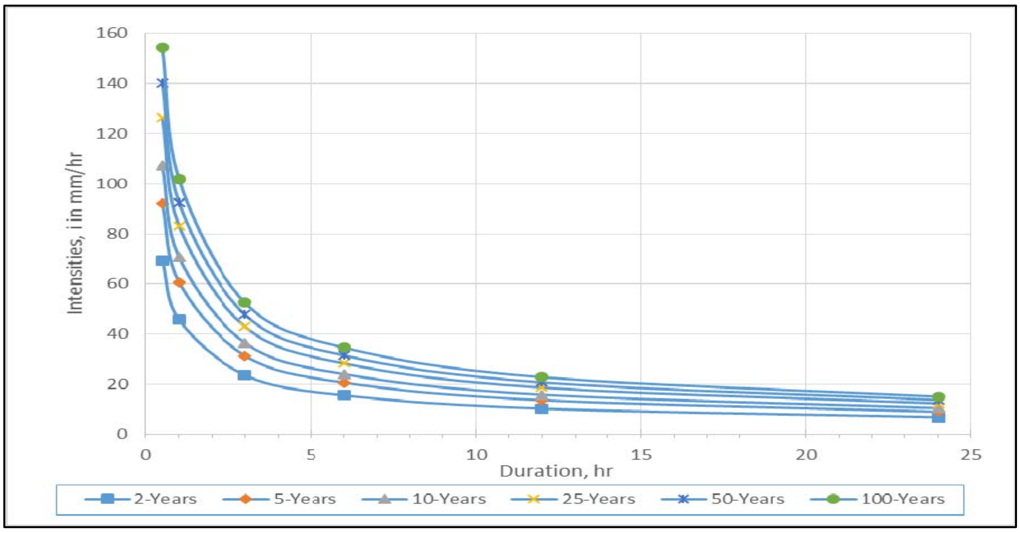

Fig. 4- Rainfall IDF curves valley for present climate at Setagaya rainfall station

Quantile-quantile bias-correction technique was applied for minimizing biases in the MRI-AGCM 3.2 precipitation frequency and intensity. Two-parameter gamma distribution was employed for frequency distribution analysis. Bias in daily GCM precipitation frequency was corrected by finding a threshold value to truncate the Gamma distribution of the raw daily GCM precipitation, such that the mean frequency of precipitation above the threshold match the observed mean precipitation frequency. The threshold was calculated by determining a value such that number of GCM and observation wet days are nearly same. The bias-correction technique was validated by comparing wet days and precipitation intensities for observation, raw, and corrected GCM precipitation data series. Fig. 5 shows the comparison of regional monthly average wet days and precipitation amounts. Biases in monthly wet days and precipitation amounts have been minimized with the use of a threshold. These observations revealed that the proposed bias-correction technique can be reliably used for correcting the biases in future GCM outputs with the use of present climate parameters. Comparison of daily extremes is highly important in the context of reliable flood simulation. Fig. 6 shows that bias-corrected daily GCM precipitation data have a far better agreement with observation precipitation than that of raw GCM. The study revealed that there will be an average increase of 29% in precipitation intensity over Tokyo study area due to climate change by the end of the 21st century in the area.

In order to understand the impacts of extreme rainfall event on flood discharge, daily maximum of 30 years was used in both present and future climate scenarios. Here, present and future daily maximum were derived from 1976 to 2005 and 2071 to 2100 rainfall data. The flood hydrographs indicated that there will be an increase of 11% to 20% in peak values at the outlet of Yato watershed under climate change consideration. Considering land use planning, it was observed that Kinuta Park is in a strategic location which can be used to construct a storage facility. Hydrologic simulations revealed that the storage facility alone is not adequate to reduce the future peak discharge to present peak discharge. The results of this study are of significant practical importance for the design, operation, and maintenance of stormwater management infrastructures under a changing climate scenario.

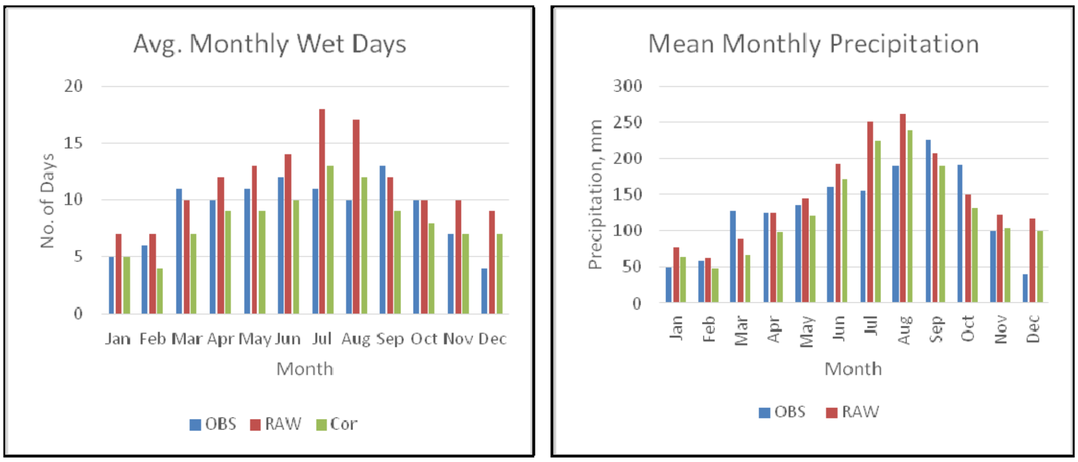

Figure 5: Comparison of mean monthly wet days & precipitation for 1976–2005 period

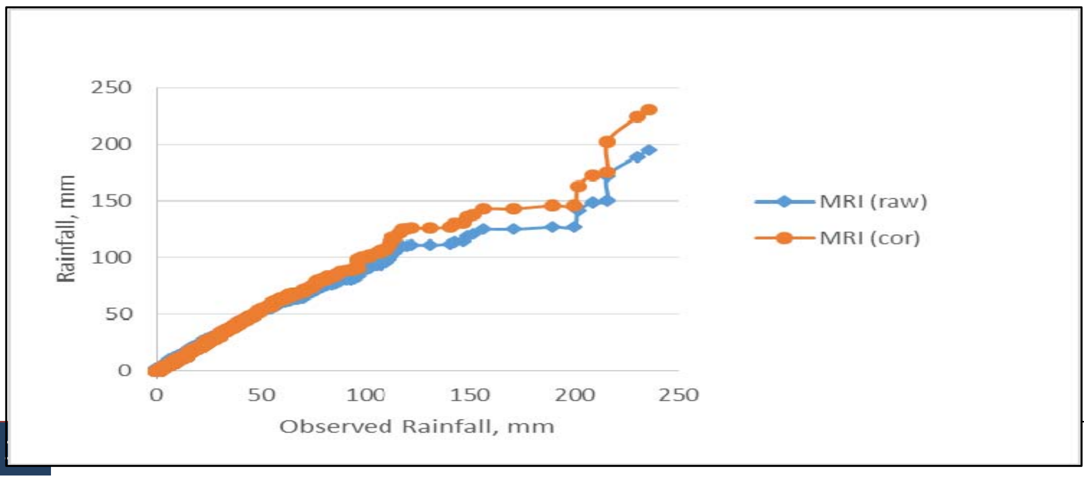

Figure 6: Comparison of daily rainfall extremes

In Hanoi, Vietnam case, the study examined the impact of climate change on rainfall IDF (intensity-duration-frequency) under different scenarios over a baseline period of 1976 to 2005 (Fig. 7). Bilinear interpolation was applied to rainfall data extracted from grid points onto station points, and the quantile mapping technique was chosen to correct for the bias of GCM (Global Climate Model) simulations in comparison with the observational data. The result was obtained by using the Gumbel distribution for frequency analysis of observational short-duration rainfall datasets from 1976 - 2005. For example, the 100-year return period, average rainfall intensity in 15 minutes is 206 mm/hr, in 1 hour is 148.3 mm/hr and in 24 hours is 18.7 mm/hr.

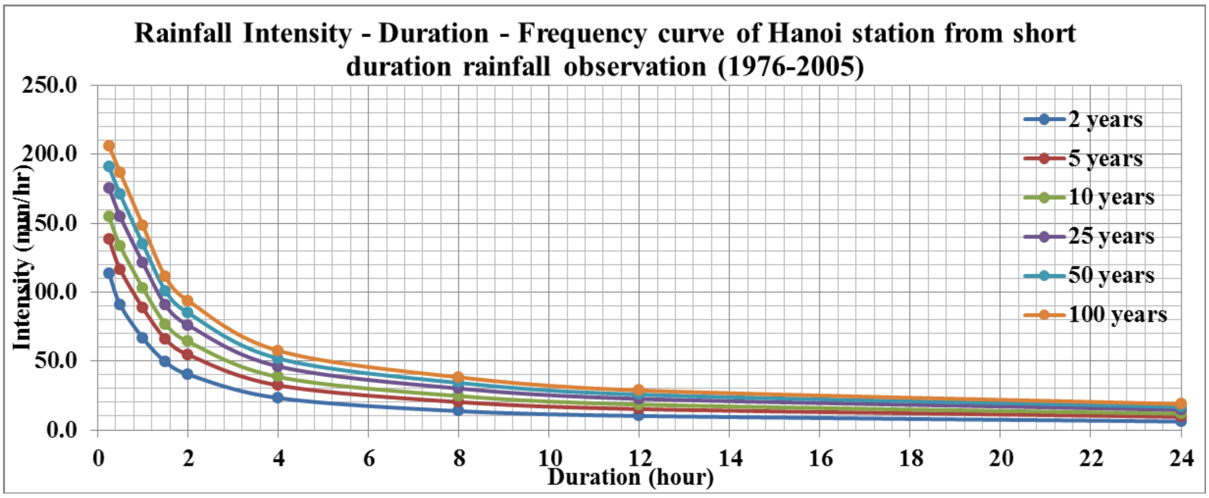

Fig 7 - Rainfall IDF curve of Hanoi station from observation data for 1976 - 2005

For future rainfall IDF (Fig 8 and 9), results from five GCMs were combined by finding the ensemble mean. Results indicate that rainfall intensity under RCP4.5 may increase much more than RCP8.5 for most durations and return periods. For the 100-year return period, rainfall intensity increases 42.6% in comparison with the baseline period under RCP4.5. The corresponding increasing value under RCP4.5 is 38.8%. This implies that by the end of the century, heavy rain may occur with extremely high intensity under both scenarios. However, the frequency of this event is very rare.

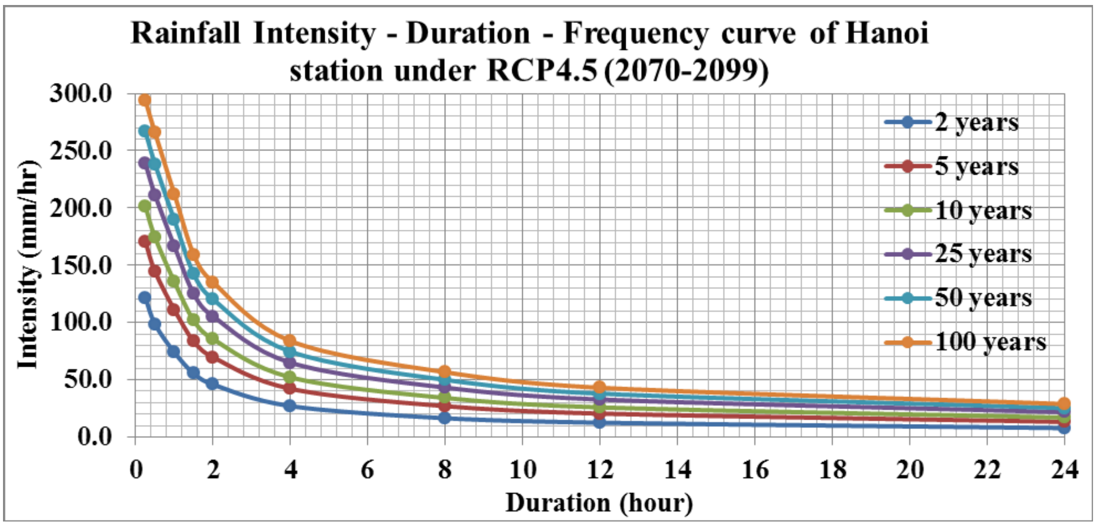

Fig 8 - Rainfall IDF Curve of Hanoi station for 2070 - 2099 under RCP4.5

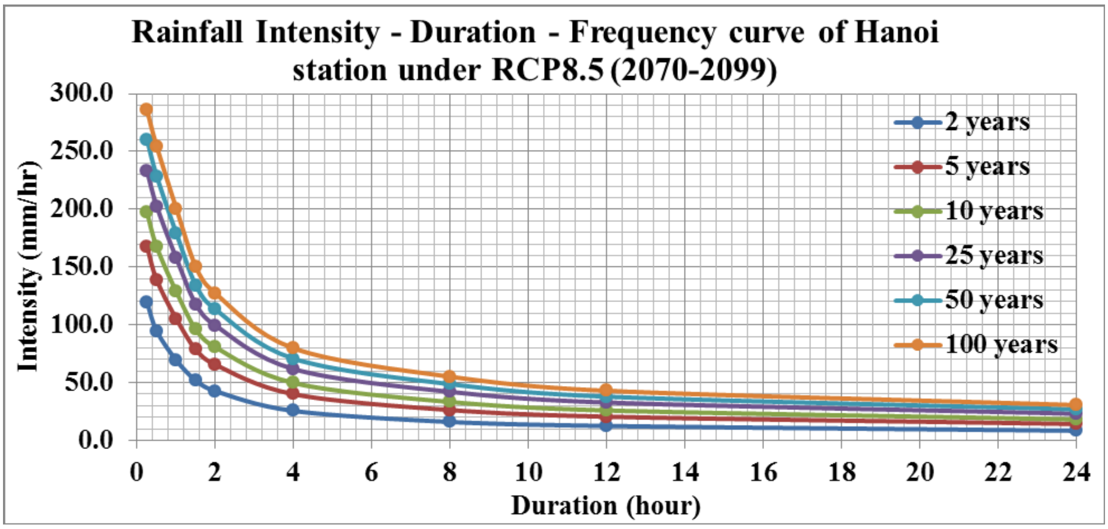

Fig 9 - Rainfall IDF curve of Hanoi station for 2070 - 2099 under RCP8.5

4. Conclusions

General characteristics of rainfall in Asian monsoon climate have been studied and synthetic design storm pattern has been developed including climate change. Among triangular shape, complex trapezoidal shape and a curved shape, the Chicago Design Storm (CDS) is found to be the best fit over Bangkok, Thailand with proposed modified peak rainfall intensities by reduction to 5 and 10 minutes intensities. Climate change consideration reflects in design rainfall pattern and shows intensity increasing at most. The quantile mapping method performed well in predicting the amount of rainfall and the number of wet days that are notably close to the observations. In addition, this method accurately captured extreme values of rainfall for all GCMs. Given a large uncertainty in projected rainfall intensity of these climate models, developing an ensemble model as a result of incorporating all climate models, performing an uncertainty analysis, and creating a probability based IDF curves could be proper solutions to diminish this uncertainty. Comparison of IDF curves for present and future climate indicated a significant increase in maximum rainfall intensities, which has major implications on planning and design of urban stormwater drainage systems.

5. Future Directions

Considering large uncertainty associated with the climate change projections for different GCMs and RCPs, selection and use of GCMs and RCPs can be further explored. The integral part of any stormwater management practice is community acceptance, and various studies have shown that if a community is more aware of the advantages, maintenance and operation problems, they are more willing to contribute in any form, so it is vital to involve the community as an integral part of any new stormwater management policy. Although this project was originally thought to carry out socio-economic component studies at a larger extent, it was largely depended on previous such studies and reports. Thus, the future study requires more attention on this lacking component.

6. References

1. Saraswat, C., Kumar, P., & Mishra, B. K. (2016). Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi and Tokyo. Environmental Science & Policy, 64, 101-117.

2. Mansoor, A., Mishra, B.K. and Herath, S. (2015). Assessing impacts of climate change on rainfall extremes for sustainable stormwater management in Yato Watershed, Tokyo, International Expert Workshop 'Towards Urban Water Security in Southeast Asia: Managing Risk of Extreme Events', pp. 213-223

3. Rehan, M., Weesakul, S. and Winai C. (2017). Development of Design Storm Pattern with Climate Change in Monsoon Asia. THA 2017 International Conference on Water Management and Climate Change Towards Asia's Water-Energy-Food Nexus.

7. Appendix

<u>Conferences/Symposia/Workshops</u>

(1) Incept workshop November 21, 2014 at Hydro and Agro Informatics Institute, Bangkok, Thailand

(2) Final Project workshop on 23rd September, 2016 at Institute for Meteorology, Hydrology, and Environment at Hanoi, Vietnam

(3) Presentations - Binaya Kumar Mishra and Abee Mansoor: Implications of climate change on precipitation extremes and urban stormwater management, AOGS 13th Annual Meeting, Beijing, 31 July to 05 August 2016.

(4) Abstracts for presentations - Binaya Kumar Mishra and Abee Mansoor: Climate change impact on rainfall intensity-duration-frequency in Yato catchment, Tokyo: Towards sustainable urban stormwater management, AOGS 12th Annual Meeting, Singapore, 2 to 7 Aug 2015.

(5) Abee Mansoor, Binaya Kumar Mishra, Srikantha Herath (2015) Assessing Impacts of Climate Change on Rainfall Extremes for Sustainable Stormwater Management in Yato Watershed, Tokyo, International Expert Workshop Towards urban water security in Southeast Asia: Managing risk of extreme events, Phnom Penh, Cambodia, 19-20 November 2015.

(6) Attended APN-GCR IGM-20, 23rd to 27th March 2015, Soaltee crown, Kathmandu, Nepal, discussion with different experts, researchers from the Asia Pacific.

(7) Discussion with MONRE (Ministry of Natural Resources and Environment), Vietnam during the visit about the project.

(8) Stakeholder engagement program during UNU visit to Yato watershed with local NGO, University and residents.

(9) Water Environment & Technology Conference, Hokkaido University, Japan (21-23 July 2017) the research finding on the "Comparative Analysis of Stormwater management and Governance: Achieving Water Security in Tokyo, Hanoi and Bangkok"

List of Young Scientists involved

1. Chitresh Saraswat, United Nations University, IAS, Reviewed and Developed strategies for efficient stormwater runoff capture, saraswat.chitresh@gmail.com
2. Abee Mansoor, United Nations University, IAS, Worked on Tokyo Case Study - Yato watershed, abee.mansoor@student.unu.edu
3. Jheel Batsia, United Nations University, IAS, Tokyo, Japan, Worked on Tokyo, Japan cases study.
4. Anjana Dahal, United Nations University, IAS, Tokyo, Japan, Worked on Tokyo case study.
5. Linh Naht Luu, Institute of Meteorology, Hydrology and Environment, Hanoi, Vietnam, Worked on Hanoi, Case study.
6. Thuh Tran, Institute of Meteorology, Hydrology and Environment, Hanoi, Vietnam, Worked on Hanoi case study
7. Mr. Dechphol Chitwatkulsiri, Asian Institute of Technology, Bangkok, Thailand, worked on Bangkok case study