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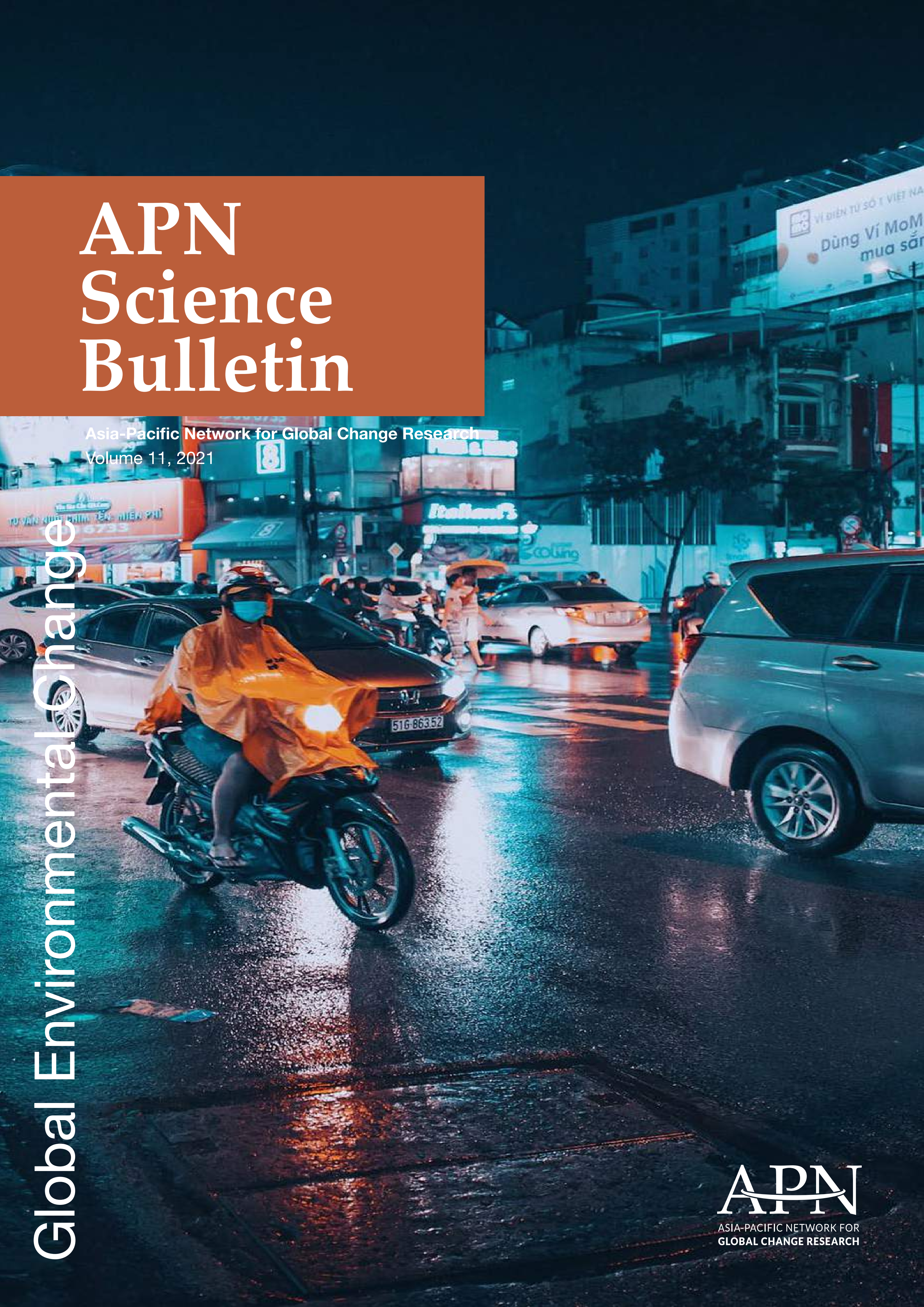

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■ The APN Science Bulletin is a peer-reviewed digital publication that features research and capacity building projects funded by APN. The Science Bulletin is intended for readers from both science and policy-making communities, as well as young scientists in the Asia-Pacific region who are keen on promoting global environmental change, sustainable development and the science of sustainability.

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Preface

Faced with another year of challenges due to the COVID-19 Pandemic, our projects have continued to face and overcome the challenges presented in conducting their work, particularly at the regional level. In this respect, we have successfully moved to hybrid (online and in-person) meetings, workshops, and conferences, which has proven instrumental for our projects to achieve their objectives.

As a result of the Pandemic, we published 12 articles in 2021 compared with 17 in 2020, but this was expected. The 2021 compilation is available in the current edition of the APN Science Bulletin, our 11th Volume, and in our Publication's Library on the APN website https://www.apn-gcr.org/bulletin/. The 12 articles featured in the 2021 edition of the Science Bulletin are regionally balanced articles published from our Comprehensive Regional Research Programme (CRRP), our Climate Adaptation Framework (CAF) and our Capacity Development Programme (CAPaBLE). They comprise 5 research papers, 3 case studies, 2 technical reports and 2 reviews. They cover a range of issues mainly related to climate change, resilience, adaptation, and climate-smart technology, with articles focussing on adaptation plans and nationally determined contributions. Others look at loss and damage, including impacts of global change from farming systems to urban infrastructure.

I am delighted to let you know that, at the time of publishing this compilation, we have had almost 23,000 pageviews on the Science Bulletin site over the calendar year 2021. There have been 277 PDF downloads of articles published in the 2021 Science Bulletin, which is our 11th edition. For all editions, we have had a total of 1,635 downloads this year alone. As a peer-review source of scientific literature in the world of global environmental change, our articles have been cited by 124 research papers.

This year marks the 25th anniversary of APN and we are fully committed to providing policy-relevant peer-reviewed scientific resources, capacity building tools and policy briefs in our publications library, which continues to be a go-to place for knowledge products that are openly accessible to all. Our Knowledge Management team strives to bring you project and activity outputs promptly to keep up with the changing international agendas on global change and sustainability.

On behalf of the Science Bulletin management team and our Scientific Planning Group Co-Chairs, I would like to extend our appreciation to the authors and 2021 Editorial Board for your contributions to the 11th Volume. It is always an honour and privilege to work with you.

At the time of writing, the Omicron variant of the virus is spreading fast and 2022 will likely bring fresh challenges, and we hope you continue to stay safe and well during these unprecedented times.

Linda Anne Stevenson

Science Bulletin Managing Editor
Head of Knowledge Management and Scientific Affairs
Deputy Head of Development and Institutional Affairs

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Technical report

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Climate smart actions "Saung Iklim" for smallholder farmers in Subang district, West Java, Indonesia

Perdinan [a,b] *, Rini Hidayati [b], Rizki A Basit [a], Raden E P Tjahjono [a], Devia Purwanti [a], Yon Sugiarto [a], Ryco F Adi [a], Wayan S Puspadewi [a], Shabrina Oktaviani [a], Yonvitner [a], Ikrom Mustofa [a], Syafararisa D Pratiwi [a], Jiří Patoka [c]

[a] Center for Disaster Studies, IPB University, Jl. Raya Pajajaran, 16153, Bogor, Indonesia
[b] Department of Geophysics and Meteorology, IPB University, Dramaga, 16680, Bogor, Indonesia
[c] Department of Zoology and Fisheries, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, 16500, Prague-Suchdol, Czech Republic
* *Corresponding author. Email: perdinan@apps.ipb.ac.id.*

ABSTRACT

The implementation of climate change adaptation for crop production is often ineffective among farmers due to a lack of access to climatic data and inadequate knowledge on how to use the available data. The project introduced the utilization of climate data via the Climate Smart Action "Saung Iklim" application to targeted stakeholders (i.e., agricultural extension workers and farmer representatives) designed to improve farm management. The term "Saung Iklim" originally means a place where people can learn about the use of climate information for farming activities. Therefore, strengthening stakeholders' capacity is an essential element of "Saung Iklim", which has been conducted via a series of training activities using various modules and focus group discussions. The project selected one of the major production centres of rice in Indonesia, namely the District of Subang. The district government formed a task force named "Tim Iklim", consisting of the targeted stakeholders, to assist the project team in delivering the targeted project outputs. The project team, in collaboration with Tim Iklim, produced the modules on utilizing simulations of crop models for managing climate risks. The involvement of the stakeholders was to accommodate their input and understanding so that the modules are ready for practical purposes. The project also equipped Tim Iklim with a dedicated website, containing crop simulation model outputs, modules, online surveys, and forums, to facilitate information delivery on managing farm risks to climate exposures.

KEYWORDS

Adaptation, Climate, Climate smart action, Indonesia, Rice, Risk

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HIGHLIGHTS

- Institutionalization of stakeholders' engagement as the Regent of Subang District signed the formation of Tim Iklim to focus on climate action.
- Practical modules are available and easily accessed via the Tim Iklim website, htt ps://pi-dev.co.id/timiklim/.
- The website stores all project outputs, i.e., crop simulation model outputs, modules, online surveys, and forums.

1. INTRODUCTION

Global climate change has been highlighted worldwide and has a significant effect on crop production (Hatfield et al., 2011; Lobell, Schlenker, & Costa-Roberts, 2011). Several studies in Indonesia reported that climate variability and extremes shifts, indicated by rainfall changes as well as rising temperature, would change rice production (Manzanilla et al., 2011; Hosang, Tatuh, & Rogi, 2012; Syaukat, 2011; Sumaryanto, 2012). In order to reduce the effects of climate change extremes, Climate Smart Agriculture (CSA) has been proved to be one of the major approaches for climate adaptation and mitigation measure. CSA is a regional framework initiated by the Food and Agriculture Organization (FAO) to apply farming technologies and practices to facilitate crop growth and production as well as development in the agro-ecosystem specific area. Observed actions improve yield or income, reduce emissions, enhance the efficiency of production inputs, and achieve resilience (Rioux et al., 2016).

However, CSA technology has challenges for implementation at the farm level in Indonesia. Shirsath, Aggarwal, Thornton, and Dunnett (2017) suggested that the promotion of CSA requires an understanding of sustainability, both the costs and benefits, and the environmental impacts of various technological interventions in the local context on current and future climatic conditions. Perdinan, Dewi, and Dharma (2018), used a rice commodity as an example to evaluate Smart Rice Actions in Indonesia, and suggested that the CSA implementation requires the capacity of farmers to properly utilize climate data and information for farming management and practices. However, farmers are facing difficulty in adopting the CSA due to limitations in knowledge and capacity, and availability of guidelines and tools (Perdinan et al., 2018; Anggarendra, Guritno, & Singh, 2016). Fortunately, the GoI strongly supports any action targeted to address the climate impacts on crop production that can hamper the self-sufficiency target. For example, the GoI issued a web-based tool with a cropping calendar named Kalender Tanaman (KATAM), ht tp://katam.litbang.pertanian.go.id/main.aspx. This tool provides information on crop sowing dates for administrative boundaries in Indonesia (i.e., provincial to sub-district).

The KATAM tool also provides advisories for areas prone to flood and drought via maps at the administrative level, although limited to use of KATAM for farmers at a specific location. As of now, KATAM does not provide information on the potential impacts of climate variability and projected climate change on crop production. However, farmers are often unaware of KATAM raising a challenge associated with communication media and limited knowledge on utilizing climate information (Anggarendra et al., 2016). Additional initiatives are needed to equip farmers with tools and guidance to manage climate risks on farming activities. Collaborative work with local actors such as local government, university, and farmers' organizations are essential to embrace the local context so that the initiatives are understood and can be adopted locally. This type of proposed initiative complies with the commitment of the GoI that lately is articulated in the National Determined Contribution (NDC) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in 2016. The NDC endorsed the need to reduce climate change risks on food through local capacity building and the application of adaptive technology (GoI, 2016).

This project strived to directly enhance the capacity of Tim Iklim (composing of local government, extension workers, farmers' groups and universities) and the rice farmers of Subang district. Tim Iklim is a formal team established by the Regent Decree of Subang No.600/Kep.251-BP4D/2017 at the forefront to enhance farmers' capacity in managing climate risks on crop production. The establishment of Tim Iklim is in line with Indonesia's NDC goal, where agriculture is prioritized as a key development sector. This is also consistent with the goals of Asia-Pacific Network for Global Change Research (APN) in its research, capacity development, and science-policy agendas. With reference to the NDC request, it is necessary to formulate capacity building programmes that ensure the transfer of knowledge to the targeted recipients.

The project strived to improve the capacity of extension workers and farmers on utilizing climate information through the implementation of Climate Smart Action "Saung Iklim" in using the Subang district as a pilot project. Specifically, the project is directed to 1) improve the knowledge and capacity of Tim Iklim in utilizing crop simulation model; 2) provide climatic driven tools to enhance farmers' capacity; 3) support the established Tim Iklim to apply climate-smart actions; 4) enhance the awareness of farmers and extension workers to collect and document farming issues and strategies through the digital reporting system; 5) recommend lessons learned for future implementation of climate-smart actions. The project team collaborated with Tim Iklim to run the project and produce the deliverables through a series of stakeholders' engagement via meetings, training, field visits and demonstration plots. The active involvement of Tim Iklim is aimed at sustaining the work to continually improve farmers' capacity to properly employ climate information.

2. METHODOLOGY

The project was mainly directed to enhance the capacity of local stakeholders of Subang district, i.e., Tim Iklim and farmers, in managing climate change risks through a capacity building program. The project team worked together with Tim Iklim to enhance the capacity and skills of the stakeholders in utilizing climate information for cropping system management. Crop models (i.e., Aquacrop (Steduto, Hsiao, Raes, & Fereres, 2009) and DSSAT (Jones et al., 2003) were introduced through training and workshops. Aquacrop, the FAO Crop Model (http://www.fao.org/aquacrop), was employed to train Tim Iklim in understanding crop water requirement, and training on DSSAT (Tsuji & Balas, 1993) was used to learn about crop models and their use for farming management and practices. Experimental fields were created in the form of demonstration plots under the management of Tim Iklim and farmers (i.e., 4 farmers and 8 extension workers). The main essence of the demonstration plots was to engage with farmers in observing crop phenology to advocate the benefits of having crop phenology records to understand crop responses to different climatic environments, i.e., high elevation (sub-district of Cijambe), middle elevation (sub-district of Pagaden, Purwodadi) and low elevation (sub-district Binong, Pamanukan). The five sub-districts are part of the rice production centres in Subang district.

The project team designed a web-based tool with a graphical user interface to ease the use of crop modelling outputs, completed with the user modules. This approach was chosen understanding Tim Iklim works together with the agricultural development office are appointed by the Regent decree to enhance the service in utilizing climate data and information to support farming practices

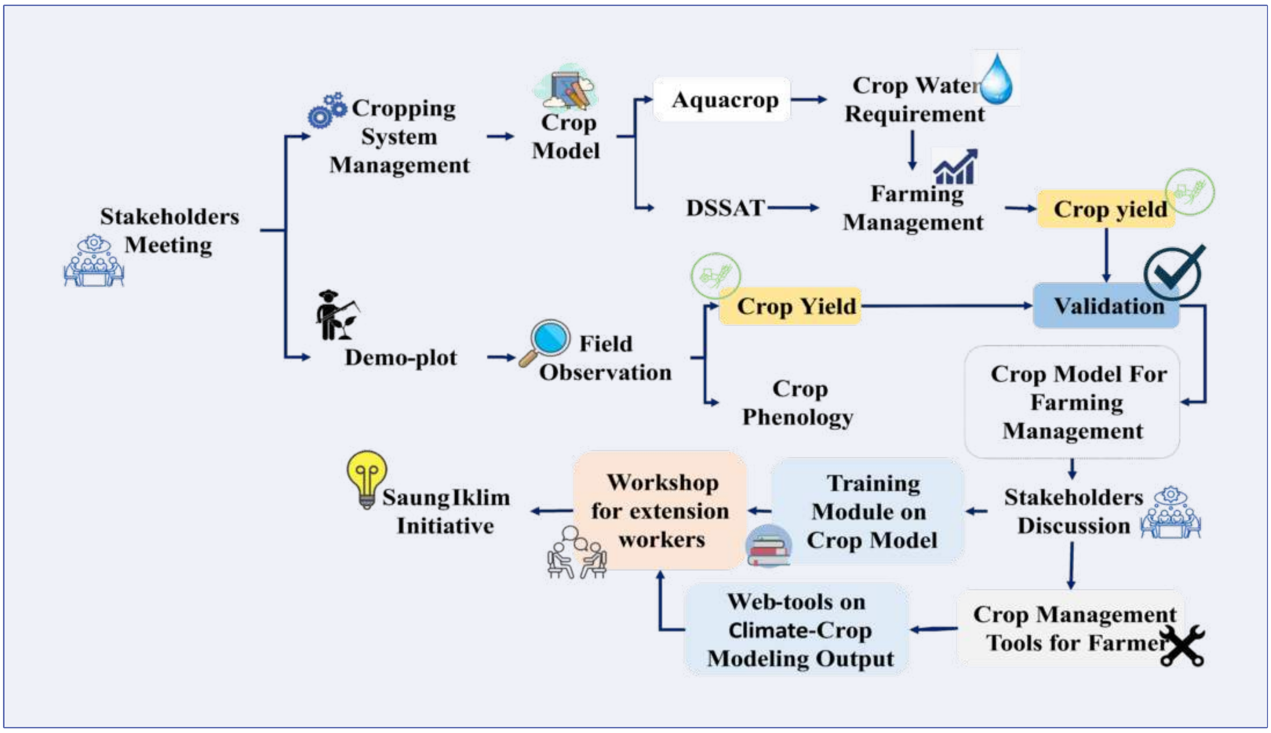

FIGURE 1. Illustration of the generalapproach for project implementation.

in the major rice-grown areas that include sub-districts of Binong; Blanakan; Ciasem; Compreng; Legonkulon; Pabuaran; Pamanukan; Patok Beusi; Pusakanagara; Pusakajaya; and Tambakdahan. The climatic driven tools were then employed for workshops and training sessions to enhance the capacity of Tim Iklim and local stakeholders comprising government officers, stakeholders, students from Subang University, team experts and assistants. All activities were stored on a dedicated website of Tim Iklim https://pi-dev.co.id/timiklim/) to initiate "Saung Iklim" as a platform to learn how to use climate information for farming management and practices on rice production as illustrated in Figure 1. Further explanation of the steps of the project implementation is provided in the sub-sections below.

2.1. Utilization of crop simulation model

Well-known crop simulation models, the FAO-AquaCrop (http://www.fao.org/aquacrop) and DSSAT (Tsuji & Balas, 1993; Tsuji, Hoogenboom, & Thornton, 1998) were employed to simulate the potential impacts of climate variability and change in different climate types of the Subang district. The simulation model provides information on the effects of climate fluctuations on planting time and productivity. As a case study, a rice crop was selected for the model simulation. This selection was made considering rice is the major crop in Subang district, acknowledged as the third main rice producers in Indonesia. Crop model simulation, i.e., DSSAT or AquaCrop, requires information on daily climate data, soil, and farming management as model inputs (Hoogenboom et al., 2010, 2019; Jones et al., 2003) , assuming pest and diseases infestations are not included so resulted in attainable yield. Daily climate data for each climate type within the Subang district were prepared based on observations whenever available. When a series of climate data are not available, available gridded climate data were employed. Soil and farming management were prepared with regards to the condition of demonstration plots. The rice cultivars used in this simulation were IR42 (for lowlands) and IR64 (for uplands), of which genetic coefficients are already available in the CERES-rice model (Singh & Ritchie, 1993) included in DSSAT.

2.2. Computer-assisted climate-driven tools

The results from the crop simulation model should be translated to a language or activity that can be understood and employed by farmers. The toolkits and/or instruments were deployed as a learning media to evaluate the effects of climate variability and change to rice productivity. The learning media was developed using a computerized web-based system to ease users so that they do not need to deal with the complexity of crop model simulation and analysis. Modules for the use of the climate-driven tools were included in the learning platform. The modules were designed to explain, step-by-step, the utilization of the climatic-driven tools. The modules were written by considering inputs from Tim Iklim and the stakeholders. The Focus Group Discussions (FGDs), workshops, and/or consultation meetings were conducted to gather input for writing the learning materials.

2.3. The field experimental showcase (demonstration plot)

The project team together with Tim Iklim and the farmers' group selected farm fields owned and cultivated by farmers to observe crop phenology in five locations for the demonstration plot. The locations were the sub-districts of Binong, Purwadadi, Pamanukan, Pagaden and Cijambe. The demonstration plots were also introduced to the students at the Department of Geophysics and Meteorology as part of the fieldwork program installed by the Institut Pertanian Bogor (IPB University) to send students to do field practice named Kuliah Kerja Nyata (KKN) – Community Service Program.

2.4. Stakeholders engagement

The engagement was designed through a systematic approach on communication sharing mechanism named "Saung Iklim". Tim Iklim coordinated the engagements through a series of FGDs, workshops, meetings, and field visits that involved government officers, extension workers, farmers' groups and local scientists. This engagement mechanism was preferred as one-shot workshop or training, hence, may not provide significant impact on the targeted beneficiaries. Tim Iklim as mandated by the Regent decree is the task force that is assigned to address climate change issues in the district. Tim Iklim managed "Saung Iklim" as a sharing media to learn the use of climate data and information for managing climate risks.

3. RESULTS AND DISCUSSION

3.1. Training on climate risk management

Climate Smart Action formulated into "Saung Iklim" is mainly designed to equip stakeholders (i.e., local government, extension officers, and farmers) to manage climate risks affecting on-farm production. One of the potential approaches to understanding the impacts of climate fluctuation on crop growth and development is by using crop models. The models simulate the interaction of the atmosphere, crop growth and development, soil condition and agronomic practices (Hoogenboom et al., 2010, 2019; Jones et al., 2003) as illustrated in Figure 2. Three training sessions on how to use crop simulation models, i.e., Aqua Crop and DSSAT, were conducted to enhance local stakeholders' understanding of the potential impacts of climate fluctuation on rice productivity. The training and workshops were targeted to about 25-30 participants (i.e., the Tim Iklim members and farmers' leaders). Modules on how to run the crop models were developed for the training, which detailed the step-by-step procedure on how to simulate rice production.

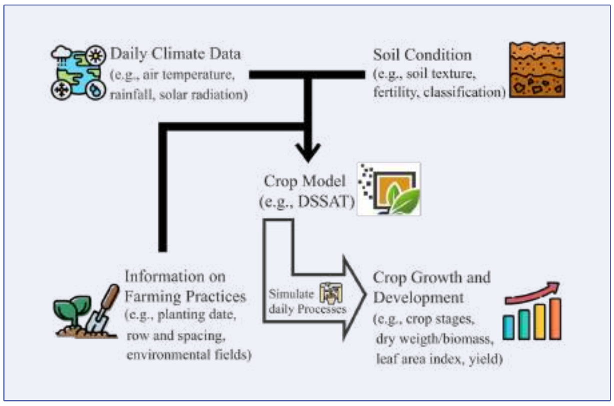

FIGURE 2. Illustrationof inputs and outputs for crop model simulation.

Considering the complexity of managing climate risks, the other modules were also developed and used for the six training sessions targeted to Tim Iklim, extension workers, and farmer representatives. The modules were designed together with the local government of Subang (Agriculture Division), extension workers, and leaders of farmer groups to gather their inputs via FGDs and stakeholder consultations. The developed modules written in Bahasa Indonesia are summarized below.

1. Module on Interpreting Climate Risk Maps. This module is designed for agricultural extension workers to guide them in reading climate risk maps of the Subang district that are grouped into seven different climatic zones and the impacts of varying rainfall to rice yields.

2. Module of Tim Iklim for Farmers Association. This module was developed by the Agriculture Division of Subang district, which articulated the languages of Module 1 to be easily understood by the members of farmers groups or associations.

3. Module on the Use of Aqua Crop Model to Simulate Rice Productivity. This module contained a step-by-step procedure to use the Aqua Crop model for simulating rice productivity. The targeted users (i.e., Tim Iklim, extension workers, and farmer leaders) were taught how climate fluctuations can affect crop productivity.

4. Module on the Use of DSSAT Model. This module explained the basic requirements to simulate crop growth and development using the DSSAT Model to the training participants.

5. Module on Field Observations. This module was intended for the demonstration plot and targeted to users who helped in observing crop phenology. This module guided observers to record phenology stages of rice starting from sowing to harvesting as well as how pest and diseases infected rice during the observation period.

6. Module on Utilization of Website of Tim Iklim. This module was designed for the targeted users (e.g., Tim Iklim, extension workers, and farmers association) and a wider audience to obtain information about the project. The website contains a tool that stores simulations of rice productivity using Aqua Crop and DSSAT models under different climate conditions for the Subang district. Project reports that explain all activities and recommendations for managing climate risks to farming activities in Subang district are also available.

3.2. Dissemination media of Tim Iklim activities

Climate information was not the main reference for agricultural activities in Subang district. However, the local stakeholders realized that climate fluctuations contributed to the failure of crop production in the district. This situation urges the need to record lessons learned from the project and disseminate the project outputs to a wider audience. The project team, together with the local government in Subang district, represented by BP4D Subang District Economic Section and Subang District Agriculture Office as well as agricultural extension workers, agreed to develop an online media as a dissemination tool. A website (https://pi-dev.co.id /timiklim/), stored information about the project activities, including photos, and published papers written by the project team members. The main page is shown in Figure 3 .

FIGURE 3. The main page of the Tim Iklimwebsite (Source: https:/ /pi-dev.co.id/timiklim/).

The website contains several menus focused on managing reports, training modules, a database of crop model simulations, and agricultural impact surveys. The gallery section contains photos of Tim Iklim's activities while carrying out activities in Subang. All modules explained in Section 3.1 are stored on the website. The modules were converted into a digital format so that they can be easily accessed and downloaded by Tim Iklim and other users.

A database of simulated Aquacrop and DSSAT models was established on the website to allow users who are not familiar with crop simulation models

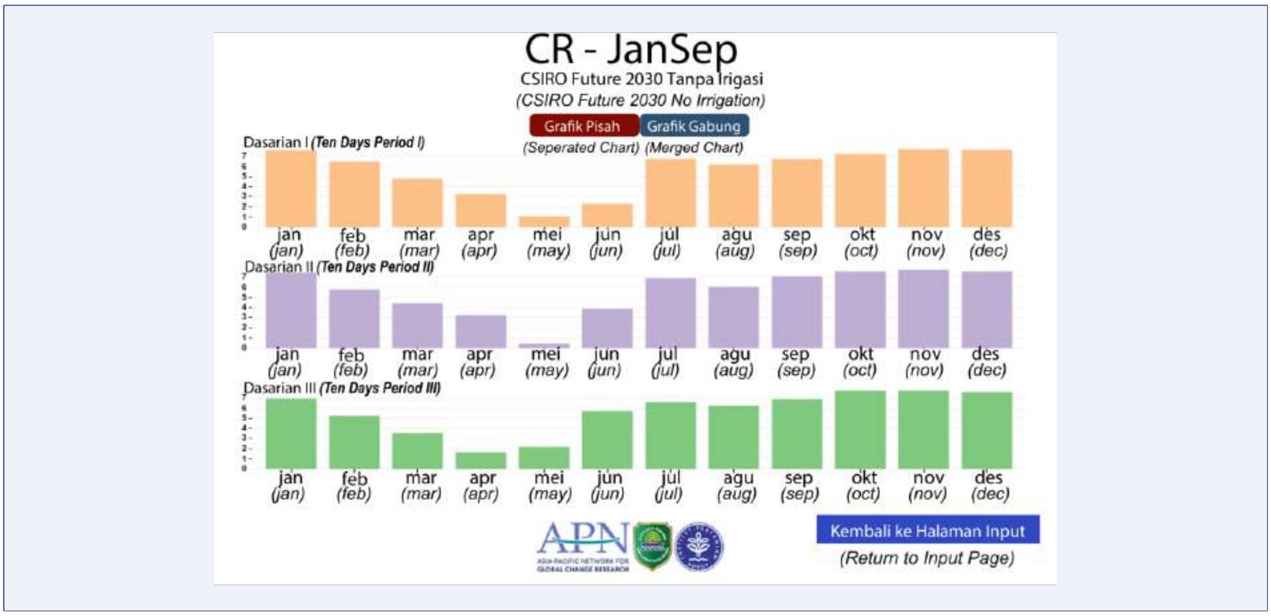

FIGURE 4. Onlineinterface of the database of rice simulation model outputs (Source: https://pi-dev.co.id/timiklim/timiklim/apnTools).

to learn about the impacts of climate variation on rice productivity. The database stored information of simulated rice productivity under different climate scenarios grown in different climate types of Subang district, which are grouped into five (5) climate clusters. The clusters were divided based on the highest and lowest rainfall values in the past 30 years. Climate scenarios were the simulation options with reference to the potential impacts of climate phenomena, i.e., climate change (projected future climate based on CSIRO and MIROC climate models) and climate variability (El Niño, La Niña, and Normal), on rice productivity. The interface of the database is shown in Figure 4 and the example of the simulation is in Figure 5. Please refer to the website for full information. In summary, the online interface (Figure 4) allows users to learn about fluctuations of crop productivity based on a set of inputs required for the system: 1) Regional climate cluster information; 2) Climatic conditions: climate change and climate variability; 3) Climate change scenarios based on climate model outputs of CSIRO and MIROC; 4) Data period and year; and 5) Rice field condition (rain-fed or irrigated). Two training sessions (on July 12, 2019, and August 15, 2019) were also conducted to ensure the website system could be used by users. The trainees were agricultural extension workers, the Subang District Agriculture Service, a joint farmer group, Subang University and the Subang Regency BP4D.

3.3. The demonstration plot

The field experimental showcase (demonstration plot) was purposed to observe plant phenology during the crop growth cycle. With the assistance of the local government and farmer leaders, the demonstration plots were chosen considering the geographical characteristics (lowland and plateau), climate conditions and characteristics of rice plants. The locations were rice fields in the sub-districts of Binong (0.35 ha), Pagaden (0.13 ha), Pamanukan (0.20 ha), Purwadadi (0.12 ha) (lowlands), and Cijambe (0.30 ha) (highlands). Climate parameters such as daily rainfall, air temperature, air humidity, evapotranspiration and crop phenology were observed using the methods listed in Table 1.

Observed climate data and soil parameters obtained from the field observations were employed to run the rice model in DSSAT. This software has been widely used around the world to explore the consequences of environmental changes and different farming practices on crop growth and development (O'neal, Nearing, Vining, Southworth, & Pfeifer, 2005; Dias, Navaratne, Weerasinghe, & Hettiarachchi, 2016). One of the variations in farming practices is the use of different crop

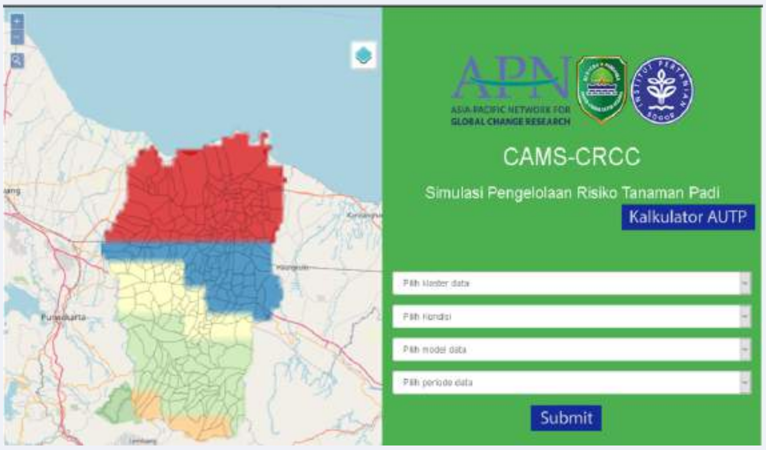

FIGURE 5. Exampleof rice productivity simulations obtained from the online database (i.e., https://pi-dev.co.id/timiklim/timiklim/apnTools). The simulations were chosen for an areawithin the climate region whose rainfalls peaked in January and September(CR-JanSep). Rice yields were simulated using projected climate data of CSIRO2030 and under the scenario of a rainfed condition. Note: the interface are inBahasa Indonesia, and the texts in the brackets are the English translations.

varieties. Except for Cijambe that was simulated using IR64, the rest of the demonstration plots ran using rice varieties of IR 42 (Table 1).

The use of varying rice varieties (IR42 and IR64) requested that users supply information on crop coefficients to distinguish the two rice varieties. Fortunately, the DSSAT model has a tool to generate genetic coefficients for different crops, and the coefficients for the two rice varieties were included in the genetic file of the DSSAT system as presented inTable 2. This requirement indicates that field experiments, particularly on testing the potential yields of different rice variety such as those frequently conducted by the Indonesian Centre for Rice Research named in Bahasa Balai Besar Penelitian Tanaman Padi (BBPadi) at http://bbpadi.litbang.pertanian.go.id/ should record the crop coefficients. The record can help minimize the costs for exploring potential areas for growing a specific rice variety as the crop coefficients can be supplied to crop model simulations such as DSSAT. Then, the crop model can be simulated using different climate data and soil conditions to examine potential areas to grow the rice variety across the country.

Furthermore, the crop simulation model allows users to learn about crop growth and development. As an illustration, simulated daily biomass was plotted throughout the crop cycle. The plots are shown for the growth of stems, leaf biomass, grains, roots, and leaf area index (LAI. The biomass of stems, leaves, grains and roots of rice increase and reach a maximum point at about 100 days after planting as illustrated in the case studies of Pamanukan and Cijambe (Figure 6). The pattern of height and number of observed tillers (Figure 7) positively related to the growth of crop biomass as displayed in Figure 6. The development of crop biomass also relates to crop productivity.

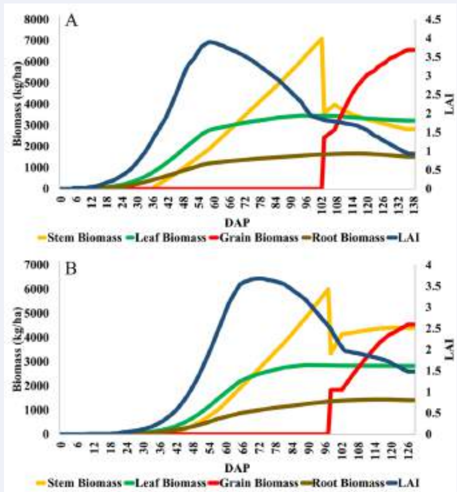

FIGURE 6. Simulation of rice growth anddevelopment in Pamanukan (A) and Cijambe (B).

Simulated rice productivity for the five demonstration plots was then compared with the rice yields harvested by the farmers. The demonstration

Data	Parameter	Observation methods	Tools
Climate	1. Rainfall 2. Air Temperature 3. Air humidity 4. Evapotranspiration	1. Measured with a rain gauge every 24 hours 2. Measured using a thermometer every day 3. Measured with wet ball and dry ball thermometer from which calculations were made4. Plant samples were taken on paint cans and weighed every 2 days	1. Simple rain gauge 2. Wet and dry bulb ther-mometer 3. Digital scales 4. Paint cans and plastic bot-tles
Phenology	Plant height and tillers	Measured with tape and calculator once a week in the vegetative phase and 4 days in the generative phase	1. Tape measurements 2. Calculator
Irrigation	Soil water level	Measured by tape following phenology observations	1. Tape measurement

TABLE 1. Observation methods used for field observations.

Coefficient	Unit	Definition	IR42	IR64
P1	°C day	Thermal unit for vegetative base phase	651	500
P2R	°C day	Day length sensitivity coefficient	120	160
P5	°C day	Thermal units are needed from the initial filling of grains (3-4 days)after initial flowering) rice to physiological maturity	580	450
P2O	Hour	The length of the critical day when developments are at their maximum rate	10.5	12
G1	(/gram)	Potential grain coefficient as an estimate of the number of grains per gram at flowering	65	60
G2	Gram	Unit grain weight under ideal development conditions (light, water, and nutrients are met, while pests and diseases are absent)	0.028	0.025
G3		Tillering coefficient	1	1
G4		Temperature coefficient of tolerance (usually a value of 1 for varieties that grow in a normal environment)	1	1

TABLE 2. Information on genetic coefficients for rice varieties used for DSSATsimulation in the study area.

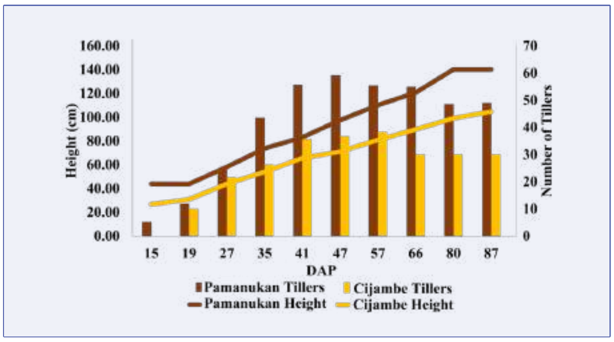

FIGURE 7. Pamanukanand Cijambe demo-plot rice plant phenology observations.

plots were cultivated by the farmers who were grown rice and allowed the Tim Iklim accompanied by the extension workers of the Agricultural Office of the Subang district to observe rice growth and development throughout the crop cycle. The harvested rice yields per hectare of each demonstration plot were estimated based on a sample plot. The sample plot called Ngubin in Subang was about 1000 m^2. The rice productivity in the sample plot was estimated based on the numbers of grains multiplied by the grain weight. The numbers of grains were calculated based on the numbers of rice clumps, the numbers of tillers for each clump, and the numbers of grains for each tiller. The extension workers and the farmers assisted the estimation (i.e., crop cutting in the sample plot) as the procedure was commonly applied in the district. The harvested yields per hectare were then compared with crop yields simulated using the DSSAT model (Table 3).

It can be seen fromTable 3 that the simulated yields closely mimic the harvested yields as the crop model parameters required to run DSSAT had

Demonstration plots	Field Estimation (tonnes/ha)	DSSAT Simulation (tonnes/ha)
Binong (IR 42)	9	8.5
Purwadadi (IR 42)	7	6.2
Pamanukan (IR 42)	6	6.6
Pagaden (IR 42)	7	5.4
Cijambe (IR 64)	4	4.5

TABLE 3. Comparison of rice productivity obtained from field estimation and DSSATsimulation.

been suited well with field conditions. This result encourages Tim Iklim to understand the potential use of the crop models for farming management. It should be noted that the main purpose of this project was to showcase the use of crop models for managing climate risk to Tim Iklim, extension workers and farmers. Therefore, the lessons learned from the field showcase, crop models, and the crop simulation database (Figure 4) offered an alternative to Tim Iklim to consider crop interactions with different climate and environmental conditions for designing proper climate adaptation strategies at the farm level.

3.4. Lessons learned through stakeholders engagement

The Focus Group Discussion (FGDs) and workshops were conducted to gather inputs from local stakeholders. The participants were officers of the Agricultural Division, academia, Gapoktan (Association of Farmers), extension workers and sub-district officers. The FGD was held from 15-16 August 2019, and discussed the modules and the Tim Iklim website. The participants explained that the developed modules were very helpful in planning management, monitoring and evaluation of farming practices. The participants justified that agricultural production inputs and facilities in the demonstration plot areas were available and accessible. There were no difficulties in the supply of production inputs.

The participants increasingly realized the need for using climate information for farming practices. This recognition is essential to encourage farmers to adopt or consider the use of climate information for farming management and practices. As of now, the Meteorological, Climatological and Geophysical Agency of Indonesia named in Bahasa Badan Meteorologi, Klimatologi dan Geofisika (BMKG), disseminate climate information and the Ministry of Agriculture utilizes climate information to suggest planting dates at the sub-district level via the KATAM application available at http://katam.litbang.pertanian.go.id/main.aspx. Thus, the results of this project can be seen as a continuation of utilizing KATAM at the farm fields using crop simulation models to predict potential yields under different climate scenarios. The crop simulation database for rice yields (Figure 4) was deployed to ease Tim Iklim as the end users in alleviating the complex procedures of running crop simulation models. The crop simulation database is integrated into the Tim Iklim website.

The Tim Iklim website was also considered useful for media sharing and learning. The modules on crop models (i.e., Aqua Crop and DSSAT) and the inclusion of the crop simulation outputs into the database integrated into the website were relatively easy to use. The participants also suggested to add more photos and illustrations following the step-by-step procedures explained in the modules. The user inputs and feedback were accommodated for finalizing the modules and the website of Tim Iklim.

4. CONCLUSION

The project activities were generally intended to equip the established Tim Iklim with proper tools and to enhance the capacity of farmers to utilize climate information for managing farm activities. Tim Iklim was established and mandated to provide climate-driven agricultural management strategies to raise awareness of the local government and farmers on the importance of utilizing climate information. The APN CAPaBLE project worked together with Tim Iklim to provide capacity building materials to help them undertake the mandate.

The implementation of Climate Smart Action "Saung Iklim" using climatic driven tools is essential to enhance the capacity of Tim Iklim and the other stakeholders (i.e., extension workers, local academia and farmers) in the Subang district. The targeted stakeholders were trained to use crop simulation models (i.e., Aqua Crop and DSSAT) and discuss the potential use of the tools to manage climate risks. Five demonstration plots were chosen to showcase the capability of simulation models and the importance of observing crop phenology for farming management. The Tim Iklim along with the local farmers learned that the climate characteristics (e.g., temperature, altitude, soil water) compounding with farming management (e.g., fertilizer application, cultivars, and planting dates) dictate rice productivity at the five demonstration plots, i.e., Binong, Purwadadi, Pamanukan, Pagaden and Cijambe.

The demonstration plots have displayed to the Tim Iklim and other stakeholders of Subang district the potential use of the two crop models for farming management. The project encourages the importance of recording crop coefficients and farming practices, which are required to run crop models. The models can mimic well daily crop growth and development only if the crop model parameters are well-suited to the field conditions. The digital media, crop simulation database and learning modules were developed as an approach to fully capitalize the new insight and knowledge from the CAPaBLE project conducted in the Subang district.

The GoI has actively encouraged the need to address climate change impacts on crop production concerning the adverse impacts of climate change (GoI, 2016). This APN CAPaBLE project has contributed to enhance the capacity of targeted local stakeholders on using climate information for farming practices. This capacity is essential to help farmers in understanding the climate-based planting tool that recommends planting dates at the sub-district level known as the KATAM application, which is available at http://katam.litbang.pertanian.go.id/main.aspx and managed by the Ministry of Agriculture. The lessons learned from the project are also expected to provide alternative tools for designing proper climate adaptation strategies at the farm level that consider interaction of crops, climate, and the environment that will dictate potential harvested yields.

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Enhancing resilience through capacity building in LCCAP formulation in the local government of Aurora, Philippines

Juan M Pulhin [a], Maricel A Tapia-Villamayor [a], Catherine C de Luna [a *], Rex Victor O Cruz [a], Aileen S Peria [a], Danesto B Anacio [b], Wilfredo M Carandang [a], Vida Q Carandang, Rose Jane J Peras [a], Lorena L Sabino [a], Dixon T Gevaña [a], Liezl B Grefalda [a], Florencia B Pulhin [a], Josephine E Garcia [a], Cristino L Tiburan Jr [a], Nico R Almarines [a]

[a] College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, 4031, Philippines

[b] University of the Philippines Manila, Ermita, Manila, Philippines

[*] *Corresponding author. Email: ccdeluna@up.edu.ph.*

ABSTRACT

Climate Disaster Risk Assessment (CDRA) and Local Climate Change Action Plan (LCCAP) provide the scientific and legal platform for climate change adaptation and mitigation in the Philippines. This APN CAPaBLE project responds to the limited technical capacity of local government units (LGUs) to comply with this requirement through collaborative capacity building. Evaluation of CDRA and LCCAP led to a National Interagency Technical and Policy Forum to formulate action plans and fast-track preparations. The initial stage of the project demonstrated collaborative advantage as a condition for mobilizing human and financial resources was enabled. Collaborative inertia set in once the technical limitations of Aurora LGUs surfaced to complete the CDRA. This mirrored the results of the institutional capacity survey, administered to 87 disaster risk reduction and management Technical Working Group (TWG) members, highlighting the LGUs limitations in data availability and functional knowledge on climate change. Thus, a shift in capacity building strategy through focused mentoring and managing LGU expectations was done. The Aurora LGUs successfully completed its CDRA and LCCAP requirements through a lengthy and arduous process. It was acknowledged that CDRA preparation has a steep learning curve and competes heavily with other multiple functions and pressing demands from the LGUs. The national interagency forum resolution suggested that the CDRA be assigned to another government agency while LGUs shift capacity development initiatives to understanding and mainstreaming scientific assessment into local plans. The project experience highlights the difficult, yet promising, path to human security development and resilience building and underscored prudence and urgency of adaptation planning at the local level.

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KEYWORDS

CDRA, Climate change adaptation, Collaborative capacity building, Human security development, LCCAP, Local government unit

HIGHLIGHTS

- The LGU's role in achieving climate and disaster resilience is crucial for a hazard-prone country like the Philippines.
- Building LGU's technical capacities in CDRA and LCCAP preparation entails collaborative process and takes time and patience to develop.
- CDRA's steep learning curve warrants a reconsideration of LGUs' tasks, which now need to focus on mainstreaming scientific assessment results into local plans.
- Climate adaptation planning by capable LGUs advances human security and risk resiliency at the local level.

1. INTRODUCTION

The Philippines is one of the countries most at risk to climatic threats and weather-related events. One of the responses of the Philippines is the passage of the Climate Change Act (Republic Act or RA 9729) in 2009, which created an enabling environment to bolster climate change governance in compliance with international frameworks and in line with national and local development initiatives (Adaptation Knowledge Platform, 2012). The establishment of the Climate Change Commission (CCC) ensued, as the agency tasked to coordinate, monitor, and evaluate programs and action plans related to climate change.

RA 9729 mandated the LGUs, as frontline agencies for climate change action, to formulate the LCCAP following the guidebook provided by the Local Government Academy (LGA) and the Department of Interior and Local Government (LGA-DILG, 2017; DILG, 2015, 2016). The LCCAP is a strategy policy that describes measures and policies of LGUs to reduce greenhouse gas emissions (mitigation actions) and increase the community's resilience (adaptation actions) to the impacts of climate change.

A total of 1,489 municipalities and 145 cities, including 81 provinces, nationwide need to prepare this action plan. The sheer number of LGUs that need to be capacitated warrants concerted efforts of government and non-government agencies, including state universities and colleges, to extend technical services for this task.

This project supported the above national priorities and built on existing initiatives towards LCCAP formulation.

1.1. Project objectives

With Aurora province as the LGU beneficiary, the project aimed to enhance its climate resilience by developing the capacity of provincial and municipal personnel in LCCAP formulation.

The specific objectives of the project were:

1. Capacitate LGU personnel on the science, impacts, and responses to climate change and the necessary tools and skills needed in LCCAP preparation;
2. Assess the vulnerability, risks, and impacts in the eight municipalities of Aurora using updated climate models, Geographic Information System (GIS), and participatory methods in partnership with the LGU personnel and other stakeholders;
3. Formulate appropriate local climate change adaptation programs, projects, and activities to reduce climate risks and enhance the resilience of the Aurora province; and
4. Enhance the resilience of services from ecosystems and social structure/human

security to different climate risks.

This paper reports on the experiences, results, outcomes, and lessons learned from the capacity building of Aurora province, including its eight municipalities, in relation to LCCAP formulation.

1.2. Description of the study site

The province of Aurora, Philippines, lies between 121°31'02" and 122°01'30" East Longitude, and 150°31'43" and 160°31'00" North Latitude, and has eight municipalities, namely: Baler, Dingalan, San Luis, Maria Aurora, Dipaculao, Dinalungan, Casiguran, and Dilasag.

Aurora province is situated in the East-Central side of Luzon Island, has a total land area of 309,860 hectares and generally mountainous and the highest forest cover density in the Philippines (Provincial Government of Aurora 2009) (Figure 1). The total population of the province is 228,046 as of 2018. It is included in the Department of Interior and Local Government's (DILG) priority targets in climate change adaptation as the province hosts a major river basin and considered vulnerable to shocks and disasters (LGA-DILG, 2017).

The province's economy is basically agricultural, with rice and coconut as the principal products, and other crops including fruit-bearing trees, vegetables, cash crops/high value commercial crops, and root crops.

The seasonal variations are as follows:

- the DJF (December, January, February or northeast monsoon locally known as "amihan") season;
- the MAM (March, April, May or summer) season; JJA (June, July, August or southwest monsoon locally known as "habagat") season; and
- SON (September, October, November or transition from southwest to northeast monsoon) season.

The climate hazards for the province include flooding, rain-induced landslide, and storm surge.

2. METHODOLOGY

2.1. Climate Disaster Risk Assessment (CDRA and LCCAP formulation

CDRA, a requirement in LCCAP formulation, is "the process of studying risks and vulnerabilities of exposed elements — people, urban areas, agriculture, forestry, and fishery production areas, critical point facilities, and lifeline infrastructure associated with natural hazards and climate change" (HLURB, CCC, UNDP, & Australian Government, 2015). Based on the DILG Memorandum Circular 2015-77, the CDRA framework consists of six steps, accomplished by completing a set of matrices:

- Step 1. Collect and organize climate change and hazard information.
- Step 2. Scope the potential impacts of hazards and climate change.
- Step 3. Develop the exposure database.
- Step 4. Conduct a climate change vulnerability assessment.
- Step 5. Conduct a disaster risk assessment.
- Step 6. Summarize findings.

Indicators and assessment scales were developed to measure exposure, sensitivity, and adaptive capacity of the following: population, natural resource-based production areas, critical point facilities, urban use areas, and infrastructure and utilities. Climate change scenarios for future risk assessments were sourced from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), hazard maps from the Mines and Geosciences Bureau of the Department of Environment and Natural Resources (MGB-DENR), and sectoral data from different municipal offices.

LCCAP formulation entails a visioning exercise, identification and prioritization of adaptation and mitigation strategies, and development of a monitoring and evaluation system. The procedure is guided by DILG's Enhanced LGU Guidebook on the Formulation of Climate Change Action Plan.

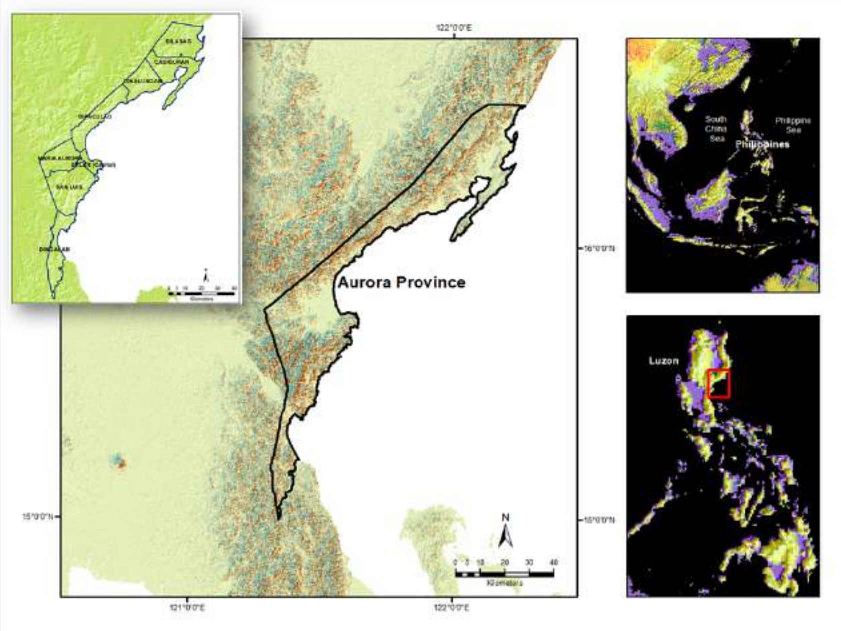

FIGURE 1. Location map of Aurora, Philippines (Sources: PhilGIS, Philippine Statistics Authority, and Global Digital Elevation Model, 2020).

The above tasks were accomplished through training, workshops, and writeshops for the Technical Working Groups (TWGs) of the Aurora LGUs from July 2017 to December 2019. Specialists from the University of the Philippines Los Baños – Interdisciplinary Studies Center for Integrated Natural Resource and Environment Management (UPLB-INREM) were assigned to each municipality to oversee progress and guide in integrating LCCAPs from municipal to provincial levels (Figure 2).

FIGURE 2. The TWG of Dinalungan, Aurora completes the CDRA matrices with assistance from a UPLB specialist during the workshop held in Baler, Aurora.

2.2. Institutional capacity analysis

The institutional capacity assessment survey was based on Friend and MacClune (2012), and Tyler and Moench's (2012) characteristics of resilient institutions: "Access Rights and Entitlements", "Information Flows", "Decision-making Processes", and "Application of New Knowledge". Additionally, Cardona et al.'s (Cardona et al., 2012) capacities for institutions to manage disaster risks in the context of resiliency were used: "Capacity to Anticipate Risk", "Capacity to Respond", and "Capacity to Recover and Change". A Likert-scale questionnaire that consists of several statements relating to each institution characteristic measured institutional capacity. Participants indicated their agreement or disagreement with each of the statements on a 5-point scale: (1) very dissatisfied to (5) very satisfied.

The survey was administered to TWG members in-charge of crafting the CDRA and LCCAP. Eighty-seven respondents/personnel of disaster risk reduction and management TWGs answered the institutional capacity questionnaire, or 97% of the expected respondents.

2.3. Capturing lessons from capacity development

Best practices and challenges in building capacities of LGUs towards the formulation of CDRA and LCCAP were documented for future activities, such as review of CDRA and LCCAP policy and guidelines. Also, sharing of learnings and experiences with another UP unit assisting LGUs, the University of the Philippines Resilience Institute (UP RI), was done. This led to the organization of a National Interagency Technical and Policy Forum on CDRA and LCCAP.

3. RESULTS AND DISCUSSION

3.1. The road to resilience: A collaborative approach towards LCCAP formulation

This capacity building initiative is no less than a collaborative endeavour between UPLB-INREM and Aurora LGUs. In this context, the experiences in project implementation will be discussed, including accomplishments and problems encountered. Focus was given on the aspect of "process", as well as concepts of "collaborative advantage" (i.e., the potential for synergy from working collaboratively) and "collaborative inertia" (i.e., relates to the often disappointing output in reality) in the practice of collaboration (Huxham, 2003) .

A Memorandum of Agreement (MOA) was signed in November 2017 between UPLB-INREM and the Provincial Government of Aurora, to build the province's capacity in developing its LCCAP. The provincial government allocated PhP 3.5 million (USD 72,280.00)[1] to include the eight municipalities and APN's CAPaBLE funds.

UPLB-INREM mobilized a team with various expertise and organized training and provision of technical assistance. In addition, a TWG was formed for the province and each municipality, consisting of heads of different key offices (agriculture, environmental, social welfare, health, and engineering among others) for the LCCAP's completion.

The initial project stage demonstrated "collaborative advantage" as all elements were mobilized, including human resources, additional funds, and an enabling environment provided by the governing body. Subsequent activities were planned, particularly the CDRA training.

[1] 1 USD = 50 PhP (2018)

From 2017 to 2019, a series of training activities were conducted in Baler, Aurora and in Los Baños, Laguna for the following activities: Participatory Risk and Vulnerability Assessment (PRVA) (Figure 3), gender analysis, CDRA and LCCAP formulation, visioning, project brief writing, prioritization of adaptation projects, and institutional capacity building.

FIGURE 3. TWG members attend the CDRA training held in November 2017 in Baler, Aurora.

Almost a year through the project, "collaborative inertia" set in. The parties were concerned with the minimal progress in CDRA vis-à-vis the enormous tasks remaining for LCCAP. It seemed that the "classroom-style training" was not effective in upskilling the TWGs. UPLB-INREM identified major obstacles and recalibrated its strategies, which included assigning a specialist to guide each TWG through the CDRA process. UPLB-INREM also reviewed the CDRA matrices and based on the Housing and Land Use Regulatory Board (HLURB) guidelines and related literature, developed indicators for exposure, sensitivity, and adaptive capacity assessment, a task previously assigned to the TWG. A rating scale was designed and equations for vulnerability and risk values were embedded in the matrices.

On 20-21 October 2019, the completed LCCAPs were presented to the municipal council for review and fiscal planning consideration. The next day, the provincial LCCAP was presented to the governor and provincial TWG and was immediately adopted, ending on a high note the more than two-year capacity building efforts for LCCAP formulation.

FIGURE 4. The UPLB project team, municipal TWGs, and UPLB graduate students complete the participatory risk and vulnerability assessment in Baler, Aurora.

The development of CDRAs and LCCAPs for Aurora and its eight municipalities can be considered first of its kind in rendering technical assistance in a capacity building setting. It went through a long iterative process that made the capacity building work. However, this approach's drawback is the prolonged implementation, which resulted in the project's request for a half-year extension.

The collaborative advantage was highly influenced by the provincial government's leadership and UPLB-INREM in creating an environment geared towards providing solutions and supportive of accomplishing the project goal. Meanwhile, the collaborative inertia was due to a lack of sufficient or updated data and unsuitable capacity building methods vis-à-vis the highly technical nature of CDRA and LCCAP. This was eventually hurdled by shifting strategies and managing municipal TWG's expectations.

Collaborative inertia was more apparent throughout this capacity building project, and fully achieving collaborative advantage between extension agents (e.g., academia or other national agencies) and LGUs presents quite a challenge, particularly in the context of decentralized functions on very scientific and strategic versus political and operational tasks. The former may be unfamiliar territory for the LGUs. Understanding the ins and outs of how science works necessitate a longer time than the period given to produce the plan. On top of this, the preparation of the plan competed heavily with other functions of the LGUs.

The CDRA and LCCAP process was both daunting and lengthy, but rewarding for both parties. Undeniably, navigating through the demanding and sometimes ambiguous process improved both parties' capacities in climate action planning. Other valuable outcomes observed were the LGUs' heightened appreciation of the CDRA and LCCAP processes and a greater sense of ownership. These conditions help instil a "moral obligation" among the LGUs to ensure that the adaptation plan is implemented, thus paving the way towards the goal of resilience.

3.2. LGUs: The frontline in climate change action

The term institution is defined as "an organization or body that has responsibility for one or more aspects of natural resource governance and development" (Moore, Zhang, & Triraganon, 2011) . Its role in climate and disaster resilience is crucial for a hazard-prone country such as the

Philippines. The capacity of LGUs to craft and implement decisions despite uncertainty spells a big difference in climate governance and ensuring resiliency against adverse impacts.

The institutional capacity survey in Aurora revealed that the municipal and provincial LGUs scored highest and performed better in disaster risk management, namely the capacity to respond (3.626), capacity to anticipate risk (3.514), and capacity to recover and change (3.513). This is not surprising as the Philippines has already set up a protocol for disaster preparation, response, and management through the Philippine Disaster Risk Reduction and Management Act of 2010. Note that in terms of institutional resilience, "capacity to respond" ranked first, which is consistent with the current institutional framework that focuses on mitigation, response, and recovery (Domingo, 2016) .

Scores for the four characteristics of resilient institutions ranked the lowest (average weighted scores below 3.5): access rights and entitlement (3.492), decision-making processes (3.460), application of new knowledge (3.383), and information flows (3.283). The characteristic "access rights and entitlement" covers the human, material, and financial resources of Aurora LGUs. Based on the LCCAP formulation experience, TWG members have limited technical capacity. Material and financial resources were also inadequate to support projects and other operations. Nevertheless, all respondents agreed that opportunities to attend training sessions were well supported by the LGU.

Summary of average weighted scores of the institutional capacity of Aurora TWGs.

The decision-making processes of LGUs follow an established protocol that encompasses the administrative, legislative and executive functions of institutions. Capacity to implement decisions scored the highest among the list of statements in this parameter.

The resilience indicator, where Aurora LGUs performed poorly, was in "information flows" including access to accurate information to guide risk and vulnerability adaptation options. The difficulty of TWGs in completing the CDRA was a testament to this due to lack of data for risk assessment and linked to a lack of financial and/or human resources for data collection and management.

The survey results mirrored both the merits and deficiencies of the Aurora LGUs in LCCAP formulation. Its completion represented a milestone in climate adaptation and institutional resilience, yet a lot of things need to be done to achieve institutional resilience, as follows:

- Improving database management systems to support scientific risk assessment;
- LGU officials need to be knowledgeable on both climate change and watershed approach;
- Monitoring and feedback mechanisms should be in place to collect historical data for probabilistic simulations; and
- Improving human, material and financial resources

3.3. Creating an enabling environment above and beyond compliance

The partnership between UPLB-INREM and Aurora LGUs noted problems in CDRA and LCCAP formulation as follows: inconsistencies in the CDRA and LCCAP guidelines (such as rating scales and systems of interest), lack of data, changes in staff involved in plan preparation, and lack of technical capacity to prepare maps. On top of these, LGUs are swamped with regulatory, operational, and management tasks, including preparing more than 30 other local plans as required by Philippine laws. Regrettably, some LGUs opted to complete the LCCAP just for the sake of compliance.

LGUs should then be provided with opportunities to facilitate proper crafting of the LCCAP. UPLB-INREM took note of all the challenges and teamed up with UP RI to discuss issues, challenges, and possible ways forward to assist LGUs in speedily crafting a more responsive climate action plan. This prompted the two units to jointly organize, together

Institutional Capacity/Resilience Indicators	Average Weighted Score	Rank
Access rights and entitlement	3.492	4
Decision-making processes	3.460	5
Information flows	3.283	7
Application of new knowledge	3.383	6
Capacity to anticipate risk	3.514	3
Capacity to respond	3.626	1
Capacity to recover and change	3.513	2

TABLE 1. Summary of average weighted scores of the institutional capacity of Aurora TWGs.

with the CCC, a National Interagency Technical and Policy Forum on CDRA and LCCAP. It was held on 7 January 2020, at the Crowne Plaza Hotel, Manila (Figure 5). It was the first of its kind to bring together different agencies to tackle this issue, focusing on each agency's role for the LCCAP mandate, the bottlenecks experienced, and suggestions to improve the overall process.

All agency presentations concluded that the CDRA process is the major stumbling block in LCCAP formulation. CDRA preparation is constrained by the following: 1) steep learning curve, including effective cascading of expertise to the LGUs; 2) lack of human resource; 3) data-intensive; 4) challenges on its sustainability (resources and resource mobilization); and 5) appreciation and accountability of LGUs.

A forum resolution was drafted with the following recommendations:

1. Institute a focal office/unit for climate change (similar to Disaster Risk Reduction Management Office) in the LGUs for compliance and accountability;
2. Coach and mentor (instead of train) LGUs in CDRA and LCCAP preparation, and requiring training for elected LGU officials;
3. For DILG, CCC and NPTE, monitor CDRA completion and mainstreaming into development plans, including ensuring the alignment of LCCAP with the Comprehensive Land Use Plan (CLUP) and Comprehensive Development Plan (CDP);
4. Tap Higher Education Institutions (HEIs) as technical service providers to LGUs in CDRA and LCCAP, and address issues on resource mobilization;
5. Create an Inter-agency Technical Working Group to develop a unified framework harmonizing the guidelines and tools (such as the probabilistic risk assessment, smooth translation from spatial to sectoral) for CDRA and LCCAP;
6. Agree on the scale of government unit for CDRA preparation (whether provincial, regional, and national) and capacitate LGUs in enhancing assessment and mainstreaming results in the plans. It is recommended that the national government prepare the CDRA, and this goes into the CLUP as a chapter; and
7. Include some data requirements for CDRA (e.g. data on the different exposure units and vulnerable communities) in the Community-Based Monitoring System (CBMS).

The resolution also calls for creating an interagency TWG to develop a unified framework harmonizing the guidelines and tools (such as the probabilistic risk assessment, smooth translation from spatial to sectoral) for CDRA and LCCAP. The resolution would be presented to the DILG.

3.4. Contribution to human security development and resilience building

Human security is one of the objectives of the Philippines' climate change framework towards achieving resilience. This is defined as "the state where the rights of the Filipino family and individuals, especially the poor and vulnerable, are protected and promoted through access to education,

FIGURE 5. Participants of the National Interagency Technical and Policy Forum on CDRA and LCCAP.

health, housing, and social protection while ensuring environmental sustainability" (NCCAP 2011-2028). Under this agenda, it is expected that the risks of climate and disasters would be reduced especially for vulnerable groups.

Climate change poses many security concerns, particularly in the areas of environment, livelihoods, health, and settlement. These include conflict over natural resources, social unrest, threats to livelihoods, population displacement, the spread of epidemics, failure in delivering social services, and other detrimental disruptions. Some security issues may be derivative, rather than immediate impacts of climate change. Nevertheless, the above affirms that climate change is development-oriented rather than a mere environmental problem Mason (2013) .

Resilience is defined as "the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions" (Lavell et al., 2012) . Resilience-building requires an understanding of the vulnerability of different components of a system. These include agents, institutions and systems (infrastructure and ecosystems); identification of key areas where intervention is crucial; and strategic planning process that highlights resilient characteristics to be achieved for each system component and the whole system in general in the context of variability and uncertainty (Friend & Macclune, 2012) .

The LCCAP as a medium for mainstreaming climate change in local development provides a blueprint for a new governance brand that emphasizes strategic foresight and system complexities while navigating through future uncertainties. The novel challenges require LGUs to be innovative, exercise anticipatory capacities, and learn from traditional and indigenous practices that have survived the changing times.

Therefore, the formulation of the LCCAP lays an important foundation towards the path of human security and climate resilience. Through this APN CAPaBLE project, the important actors for resilience building, i.e., the local government units or institutions, were trained not only to comply with but to internalize the LCCAP formulation process leading to a robust risk assessment, specific entry points for actions, a vision for managing an uncertain future, and context-specific adaptation strategies. The problems encountered and lessons learned also led to important recommendations that are hoped to facilitate the country's LCCAP formulation process through relevant policies.

While it may be hard to tell whether the recipient LGUs have achieved resilience since the LCCAP is yet to be implemented, what is certain is that the seed for building it has been planted. A more favourable environment for its growth has been defined, specifically in easing the technical responsibilities of the LGUs and building their capacities for effective utilization of risk assessments as an integral part of local development plans.

4. CONCLUSION

The UPLB-INREM and Aurora LGUs demonstrated that a collaborative process is a key approach in building capacity of LGUs for LCCAP development. A formal arrangement through MOA provided an enabling condition that guaranteed commitment and accountability of both parties and paved the way for immediate mobilization of human and financial resources.

Technical capacities, particularly for CDRA, took time and patience to develop, leading to collaborative inertia. A focused mentoring translated into significant accomplishments but entailed additional work. It is then better to manage LGU expectations as probing into institutional capacity revealed limitations in data availability and functional knowledge on climate change.

While the Aurora LGUs successfully completed the LCCAP, the impediments that the process revealed warranted a reconsideration of expected tasks. Time is crucial in climate response, and lengthy planning process could jeopardize systems that are already vulnerable and may be problematic in fitting in LGUs' fiscal plans. Although commissioning specialists to satisfy this requirement is an option, lack of appreciation on the process could be a hindrance in promoting a sense of ownership and a lure to comply for compliance sake.

With this, the National Interagency Technical and Policy Forum on CDRA and LCCAP recommended facilitating the LCCAP process by addressing CDRA's steep learning curve. It includes freeing the LGUs from the CDRA procedure and shifting capacity building to understanding and mainstreaming this scientific assessment into adaptation plans.

It is yet to be seen how the above recommendations would be acted on by relevant authorities at the national level. Nevertheless, this capacity building initiative, which ended with the formulation of LCCAP and an evaluation of this process, highlights the development nature and resilience-building objective of adaptation planning, which should be accomplished with both prudence and urgency.

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Case study

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Rapid mapping technique for data acquisition: The case of a summer school in the Banjarnegara district, Indonesia

Dewayany Sutrisno [a *], **Mazlan Bin Hashim** [b], **Peter Tian-Yuan Shih** [c], **Rongjun Qin** [d], **Rahman Syaifoel** [e], **Pramadita Witjaksono** [f]

[a] Indonesian Society for Remote Sensing, Cibinong, 16152, Indonesia
[b] Universiti Teknologi Malaysia, Baru Johor, 81310, Malaysia
[c] National Chiao Tung University, Hsinchu, 1001, Taiwan
[d] Ohio State University, Columbus, 43210, OH, USA
[e] EuroUSC International, Cardinal Point, WD3 IRE, Rickmansworth, UK
[f] Jl. Kaliurang, Sekip Utara Bulaksumur, 55281, Yogjakarta, Indonesia
[*] *Corresponding author. Email: dewayany@gmail.com.*

ABSTRACT

Global environmental change makes us aware of the impact of natural hazards. Natural hazards are phenomena with large spatial dimensions and impacts but whose mapping and monitoring data can be recorded only by using satellite or aerial remote-imaging platforms (Poursanidis & Chrysoulakis, 2017). Given that Southeast Asia is the region in the world that is most vulnerable to disasters, it is necessary to implement capacity building for the young scientists in this region so that integrated disaster communities can be developed in their respective countries and possibly in the whole of Southeast Asia. This can be done through summer school, one of the best ways to transfer knowledge. The purpose of this article is twofold: (1) to explain the use of summer school to improve young scientists' knowledge and understanding of rapid-mapping techniques; and (2) to perform a qualitative assessment of a summer school for rapid-mapping projects. The results of this project showed an increase in the basic science knowledge of the summer school participants (representatives of eight Southeast Asian countries) in terms of initial disaster data provision, field data acquisition using unmanned aerial vehicles, and the rapid-mapping system development design.

KEYWORDS

Disasters, NDVI, Rapid mapping, Southeast Asia, Summer school, UAVs

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HIGHLIGHTS

- Summer school employing the face-to-face method for sharing knowledge related to rapid mapping can improve the basic science knowledge of the participants.
- The unmanned aerial vehicle (UAV) technology is the best technology for acquiring detailed field data.
- The rapid-mapping method (RapMet) may consist of the normalized difference vegetation index (NDVI), linear enhancement, image fusion, and orthophoto map development.

1. INTRODUCTION

1.1. Background

Natural disasters affect a large number of vulnerable communities in the world annually. Southeast Asia is the region in the world that is most prone to disasters. More than 41% of the world's natural disasters occur in this region, and the region is exposed to almost all types of hazards (Guha-Sapir, Hoyois, & Below, 2015) . Emergency responses and humanitarian actions are usually provided in the communities in disaster areas. For these reasons, spatial information or mapping the impact areas are needed. For rapid humanitarian action, remote-sensing technology can provide faster and more accurate spatial information on disaster areas.

Rapid mapping and monitoring using remote-sensing techniques are potentially useful technology for providing rapid information on disasters for decision-makers (Bühler, Kellenberger, Small, & Itten, 2006). As such, Rapid-Mapping Method (RapMet), which integrates near-real-time-acquired remote-sensing data with spatial data acquired from unmanned aerial vehicles (UAVs) and with local knowledge, was developed for use in Southeast Asia. The early careers in the region need to acknowledge and use RapMet and thus help disseminate it to their communities. Therefore, a capacity-building initiative, summer school for early careers was used for sharing knowledge about RapMet within the Southeast Asian region.

1.2. Aims

This article aims to explain the implementation of summer school to improve young scientists' knowledge of rapid mapping and to perform a qualitative assessment of the summer school implementation.

1.3. Study area

Landslides are frequent hazards in Southeast Asia. In Indonesia, the Banjarnegara district is one of the districts in the country where landslides occur annually. It was thus selected as the study area. More than 90% of Banjarnegara consists of undulating, hilly, and steep slopes with high-saturation soil types that have been cleared for use as agricultural lands. High-intensity rainfall, a soil type with a crumb structure, saturation, and slope may cause massive landslides in some parts of the district (Widjaja, Naba, & Amartiawati, 2016).

2. METHODOLOGY

2.1. Capacity building

Summer school is a capacity-building initiative that was chosen for this project for sharing knowledge and developing a network among young scientists. Summer school programs focused on accelerated learning have a positive impact on the knowledge and skills of the participants (Cooper, Charlton, Valentine, & Muhlenbruck, 2000). Indeed,

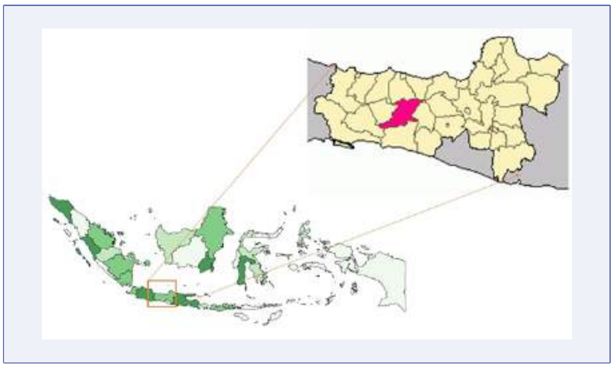

FIGURE 1. Banjarnegara district study case.

according to Sida (Bergström, 2002), education and training (as in the summer school framework) are the best ways to improve young scientists' knowledge about science. As this study focused on the Southeast Asian region, the summer school participants were representatives of eight Association of Southeast Asian Nations (ASEAN) member countries (i.e. Indonesia, Malaysia, Philippines, Vietnam, Thailand, Cambodia, Myanmar and Brunei Darussalam). The modules of the school had to meet the criteria for rapid mapping for disasters: basic knowledge of disasters; data acquisition method (either downloading the imagery data or field mapping); how to download and operate the open-source software; the remote-sensing digital-analysis process for disasters (e.g. image enhancement using normalized difference vegetation index [NDVI] and image fusion); mapping using UAVs, and sharing spatial data via WebGIS. Both theory and practice were taught. A simple rapid-mapping system, RapMet, was also developed prior to the summer school for sharing information. The basic method applied for this project was the face-to-face sharing method either in class or in the field.

2.2. Rapid-Mapping Method (RapMet) development

Disasters require quick and precise information for timely and effective emergency response and humanitarian aid. In relation to the provision of spatial information, remote sensing is a fast and reliable source of data. The development of RapMet as a teaching tool for summer school and the steps of sharing knowledge about it are illustrated in Figure 2.

RapMet acquires remote-sensing data in near real-time as preliminary information for determining disaster areas and the general features of such areas. However, near-real-time remote sensing cannot provide detailed information related to a disaster area. In disaster systems, remote-sensing data with a high temporal resolution, but a low spatial resolution can provide only initial information. More detailed information can be obtained only through field mapping. As such, it is necessary to have a tool that can map a disaster area without compromising the surveyor's safety. The UAV technology, among others, can be used for this purpose. The initial experience with the use of such technology showed that the combination of aerial surveys using UAVs and the collaborative sharing of such with domain experts results in richer information (Ezequiel et al., 2014). The process of rapid-mapping development is illustrated in Figure 3.

2.2.1. *Multi-sensor remote sensing: Near-real-time analysis*

Analyzing medium-temporal-resolution satellite images such as those from Landsat 8 OLI and Sentinel to assess environmental conditions and infrastructure is a possible prior analysis that can be employed. These two types of images can be freely downloaded. The fastest method of analysis is by simply identifying a disaster area after the images have been quickly rectified using international/national standards such as SRGI 2013 (Indonesian Geospatial References System, 2013). The NDVI method is used to identify disaster areas. According to Liu, Stanturf, and Goodrick (2010), the use of the NDVI method to assess environmental change and disasters provides rapid and straightforward information.

2.2.2. *Pan sharpening: Image fusion*

Pan sharpening or panchromatic sharpening merges high-resolution panchromatic images with lower- or high-resolution multi-spectral images to obtain better or higher-resolution spectral images (Palsson, Sveinsson, & Ulfarsson, 2014;

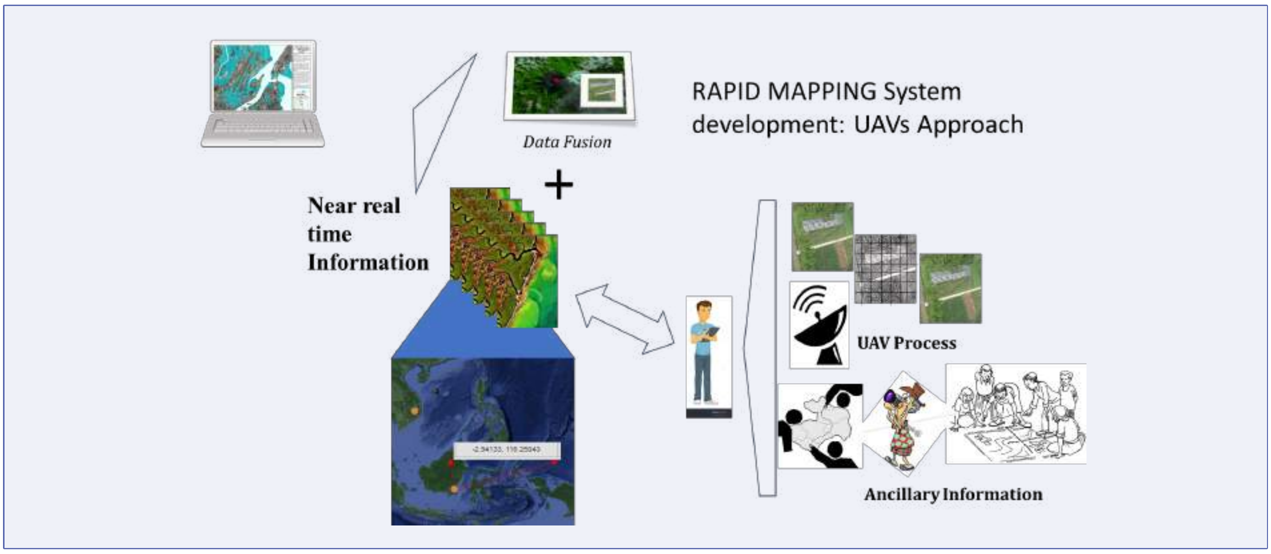

FIGURE 2. Illustration of the rapid-mapping concept (reproduced with permission of Sutrisno et al, 2017).

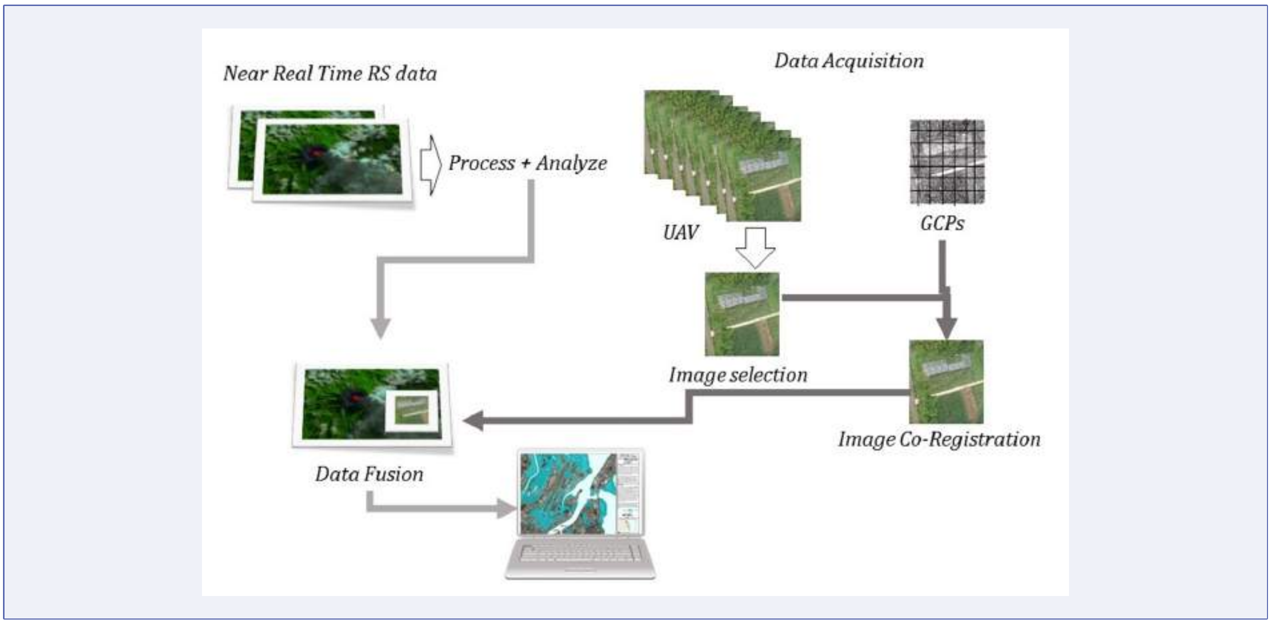

FIGURE 3. Process of rapid-mapping development (reproduced with permission of Sutrisno et al., 2017).

Rajendra, Varghese, Annadurai, Vaithiyanathan, & Thamorathan, 2012). In this case, the disaster area's Landsat 8 OLI-derived map is fused with the area's Sentinel image. The process of obtaining a new pan-sharpened image involves using a simple Brovey transformation method combined with a high-pass filter. High-pass filtering is the best way to map infrastructure or other information not available in the previous optical images. This method merges the high-frequency panchromatic image data with the multi-spectral image data to obtain a higher-resolution multi-spectral image.

2.2.3. *UAV data acquisition and processing*

High-spatial-resolution remote-sensing data are needed to obtain reliable information in the event of a disaster quickly. UAVs equipped with compact digital cameras can be used to map landslides quickly and at a high ground resolution (Niethammer, James, Rothmund, Travelletti, & Joswig, 2012). The process of obtaining spatial information using UAV-acquired data is illustrated in Figure 4.

For this step, the images acquired from the UAV should be able to capture the 60% forward and side overlaps and the ground control points

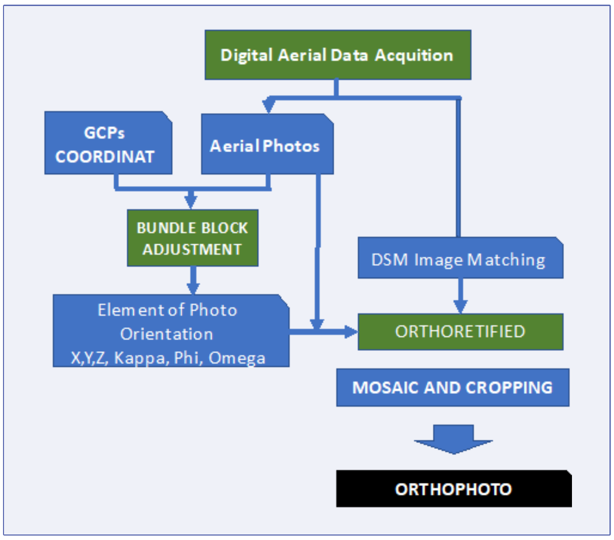

FIGURE 4. Process of obtaining spatial information from UAVs (Gularso, 2017).

(GCPs) using the conventional surveying method, which should collect more than nine GCPs. Ancillary data should also be collected, and manual or digital UAV image selection should be made prior to the orthophoto map development. The selected UAV images are co-registered using the UTM standard and the conventional photogrammetric method.

2.2.4. *Uploading the orthophoto map onto RapMet*

The orthophoto-derived map is then merged with the near-real-time-acquired images. This spatial information is preliminary information that can be further processed for post-disaster management purposes.

2.3. Evaluation of summer school

Qualitative analysis was used to determine how much the study participants learned what was taught in the summer school. This was done by reviewing the participants' assignments and personal opinions on the lessons. The amount of learning was ranked from 0 to 4 (i.e. 0 = no basic knowledge [the participant did not learn anything about what was taught in summer school]; 1 = very low basic knowledge [the participant learned only a little about what was taught in summer school]; 2 = low basic knowledge [the participant acquired a moderate amount of learning from what was taught in summer school]; 3 = mid-basic knowledge [the participant acquired a slightly high amount of learning from what was taught in summer school]; 4 = high basic knowledge [the participant fully learned everything that was taught in summer school].

3. RESULTS AND DISCUSSION

3.1. Data acquisition and processing

The implementation of summer school, which was attended by young scientists representing only eight ASEAN member countries (excluding Singapore and Lao PDR), showed an acceleration in the attendees' acquisition of science knowledge in the field of rapid mapping (Table 1).

Significant acceleration of knowledge acquisition was obtained in UAV data acquisition and processing, as reflected in the modules on open-source software downloading and operation for UAV image processing, GNSS and orthorectification, selecting and image mosaicking, and UAV concept (Table 1). The participants were able to grasp the kind of software used to process the images obtained from the UAV platform. They came to understand how to operate the software to obtain an orthorectified image. They also better understood the GNSS concepts and theories and the orthorectification processes required to obtain orthorectified-image data. In addition, the participants came to fully understand UAVs, particularly the related regulations, UAV technology development, how to fly UAVs, how to acquire data using UAVs, and how to select and mosaic images using the software. Most participants had not tried acquiring image data using the UAV platform prior to the summer school, not even converting image data into an orthorectified image. Thus, the knowledge they acquired about this was new to them, and they found it exciting that they had come to understand how to map a disaster area rapidly and on a detailed scale.

Despite the increase in the participants' knowledge, participant eagerness for practising data acquisition using UAVs was not fully achieved, as reflected by the level of knowledge that the participants acquired on average on UAV field practice and field data acquisition (less than 4). In-class computer simulation practice in flying UAVs,

No.	Materials	* Level of knowledge		Note
		Background	Summer school	
1	Basic knowledge about disasters	3	4	
2	Remote-sensing data acquisition from the system	3	4	
3	Open-source software downloading and operation for image processing	3	4	
4	Open-source software downloading and operation for UAV image processing	0	4	
5	Digital image processing – image enhancement	3	4	
6	Digital image processing – image fusion	3	4	
7	Global Navigation Satellite System (GNSS) and orthorectification	2	4	
8	UAV concept	2	4	
9	UAV practice	1	3	Needs more practice
10	Field data acquisition using UAV	1	3	Needs more practice
11	Selecting and image mosaicking	2	4	
12	WebGIS	2	3	Needs more practice
13	RapMet system concept	0	4	

* 0 = no basic knowledge; 1 = very low basic knowledge; 2 = low basic knowledge; 3 = mid-basic knowledge; 4 = high basic knowledge.

TABLE 1. Level of knowledge of participants to RapMet material.

in-class practice in flying mini-UAVs, and field practice in flying UAVs require extensive skills that may not be developed within four days of summer school. The participants should continue to improve their UAV flying skills beyond the summer school to obtain spatial data from UAVs in the future.

Knowledge acquisition acceleration also occurred on multi-sensor remote sensing modules–near-real-time analysis and pan-sharpening–image fusion. The participants understood the importance of using the NDVI and linear enhancement methods to quickly identify disaster areas and the surrounding environment as initial information. NDVI can help predict unfortunate natural disasters for the prompt provision of humanitarian aid, for damage assessment, and the formulation of new protection strategies through the changing of vegetation cover (Gandhi, Parthiban, Thummalu, & Christy, 2015). Even the accuracy assessed based on independent data on natural disasters was high (76% correct) for the NDVI-based map (Lupo, Reginster, & Lambin, 2001). The remote-sensing images used for these methods are the Landsat 8 OLI-derived images (acquired before and shortly after the disaster) and Sentinel A-derived images (acquired before and after the disaster).

The summer school participants also grasped the importance of image fusion methods between optical and radar data for quickly and clearly identifying disaster areas. Due to the availability in the near future of near-real-time-acquired synthetic aperture radar (SAR) images from multiple satellites, the fusion of SAR images with other images and data is playing an increasingly important role in understanding and forecasting natural hazards (Lu, Dzurisin, Jung, Zhang, & Zhang, 2010). Indeed, image fusion helps achieve high spatial and spectral resolutions by combining images from two sensors into one new image containing information whose quality cannot be achieved otherwise (Flusser, Sroubek, & Zitova, 2007). Image fusion helps sharpen the image map for determining disaster areas (Garzelli, Capobianco, & Nencini, 2008; Wan & Qin, 2011). See Figure 6 for the result of the use of image fusion for this purpose.

The most important part of the summer school's knowledge-sharing program is how to convert the map data derived from near-real-time-acquired images into more detailed and accurate information using UAVs. Considering the rapid UAV technology development and the

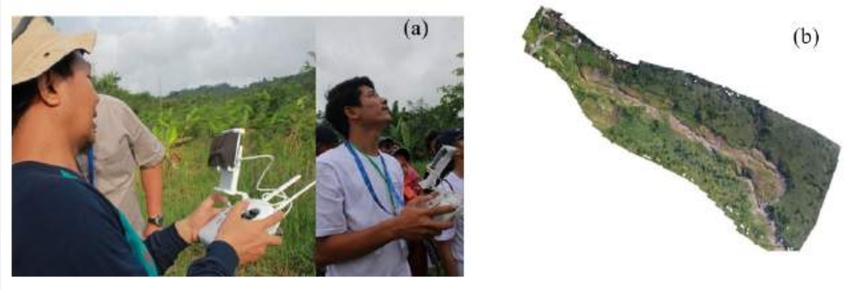

FIGURE 5. Field data acquisition (a) and orthophoto map derived from UAV data (reproduced with permission of Sutrisno et al., 2017) (b).

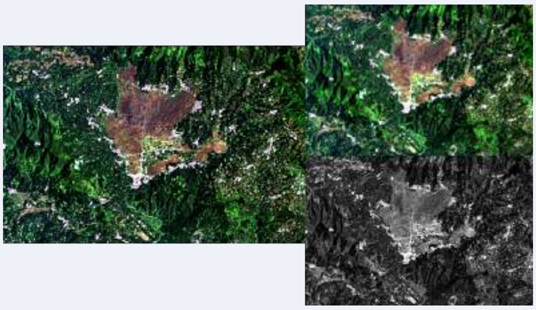

FIGURE 6. Disaster area identified using linear stretching, NDVI, and image fusion (reproduced with permission of Sutrisno et al, 2017).

fact that mappers or surveyors safety will not be compromised in the field, mapping disaster areas using UAV is a good option. This is because UAVs can quickly record disaster areas. Indeed, the methodologies, techniques, and software for creating orthophoto images from UAV-acquired data are already available. This view is supported by Adams and Friedland (2011). They state that UAVs' inherent characteristics, such as their small size, manoeuvrability, and low cost, make them a viable option for use in disaster events.

As mentioned earlier, for the summer school participants in this study, how to create a rapid map from UAV-acquired data technically and conceptually is a new scientific knowledge because most of them had not tried recording objects on Earth using UAVs and did not know how to create maps using UAV-acquired data before the summer school.

Ideally, summer school participants can acquire field data and process these into useful spatial information. However, considering the time constraints and the participants' lack of skill and experience in flying UAVs, what is important is that they be given a chance to learn and practice how to fly UAVs, acquire data from these, and process such data into spatial information.

3.2. Understanding RapMet

All the data collected and integrated using RapMet can be made easily accessible and visible to decision-makers and end-users in near real-time and worldwide using WebGIS technologies. The user will perform a query on certain data from his client application generally running within a Web browser. The results will be provided by a remote server to the Web browser. Such functionalities are the core of the so-called decision support systems (DSSs), which provide online access to multiple users and allow users to manage critical situations and make decisions in a very short time.

Although the summer school participants in this project were not fully able to practice WebGIS RapMet's development to obtain basic spatial information on disaster areas, the concept and development of such methods were fully provided in the open-source software and were understood by them. In addition, the method can be further developed for the participants' needs in the future (see Table 1). What the participants should understand about the development of RapMet is shown in Figure 7.

The results of uploading data into the system are shown in Figure 8.

4. CONCLUSION

Summer school employing a face-to-face method for sharing knowledge related to rapid mapping can improve the basic science knowledge

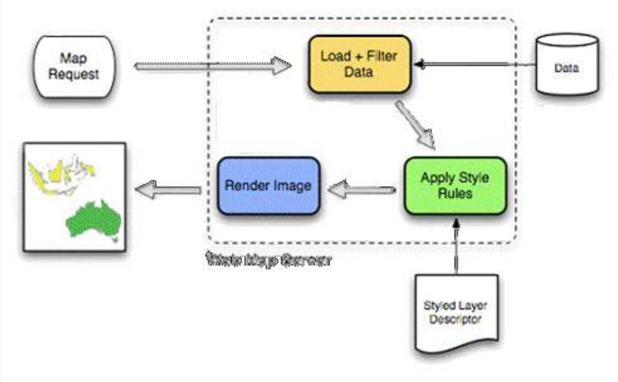

FIGURE 7. Process of RapMet development.

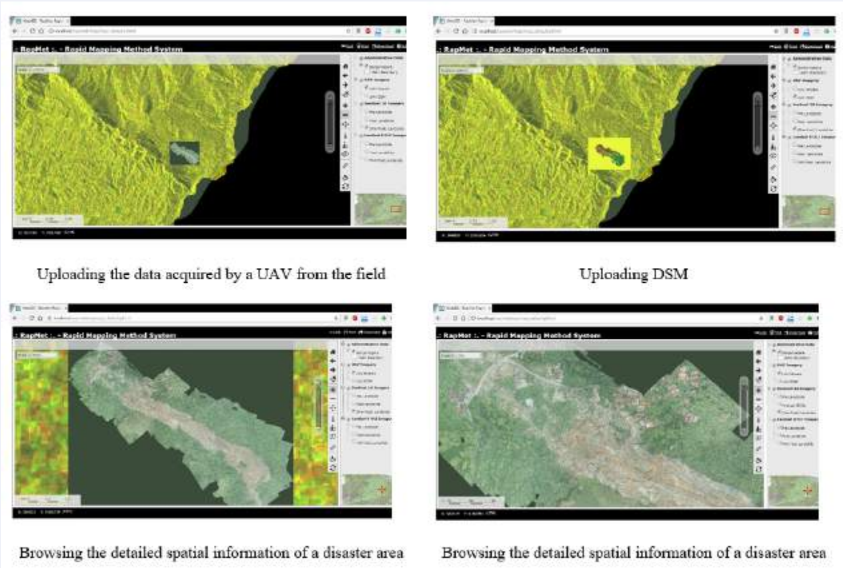

FIGURE 8. Uploading the orthophoto map into the RapMet system (reproduced with permission of Sutrisno et al., 2017).

of the young scientists that attennd, especially on UAV data acquisition and processing, WebGIS, and RapMet. Even though there were time constraints on learning about RapMet development, the basic concept of RapMet development was fully learned by the summer school participants in this study. In the future, these young scientists can further develop such a method using the basic knowledge that they obtained from the summer school. They can also introduce it to their disaster prevention authorities.

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Original article

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Assessing potential loss and damage for flood hazard using an econometric modelling technique

Senaka Basnayake [a] *, **Mehmet Ulubasoglu** [b], **Muhammad Habibur Rahman** [b], **Sarath Premalal** [c], **Lalith Chandrapala** [c], **Madan Lall Shrestha** [d], **Susantha Jayasinghe** [a], **Niladri Gupta** [a]

[a] Asian Disaster Preparedness Center, 10400, Bangkok, Thailand
[b] Deakin University, Burwood, 3125, VIC, Australia
[c] Department of Meteorology, 00700, Colombo, Sri Lanka
[d] Small Earth Nepal, Kathmandu, 44600, Nepal
* *Corresponding author. Email: senaka_basnayake@adpc.net.*

ABSTRACT

Agriculture production largely depends on weather conditions and is extremely prone to natural hazards. A more frequent and severe occurrence of natural hazards such as storms and floods has put food security at increased risk in recent decades. Evaluating the true impact (loss and damage) of disaster in the agriculture sector is very challenging. The present study focuses on using a randomized field experimental approach at both district and micro agricultural-plot levels to investigate the impact of floods on agricultural yields in Sri Lanka and its effect on farmers who are averse to taking risks and those who are willing to take risks. A detailed site selection technique has been used in the study. The dissimilarity in difference estimates indicates that flood-affected households have experienced the loss of paddy and non-paddy crops. However, the net loss of non-paddy is higher than that in paddy. Farmers offset this loss by expanding crop cultivated areas that utilize soaked fields after the flood, though there are risks of pest attack and diseases. The results are not driven by household-specific characteristics and are robust to several specifications, different crop types and alternative flood-severity measures.

KEYWORDS

Econometric modelling, flood hazard, loss and damage, yield loss

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HIGHLIGHTS

- The study investigated the effect of floods on agriculture production and farmers' coping mechanisms to loss.
- An econometric model is a robust method to assess loss and damage in different flood incidents and at different intensities.
- The study utilized micro-plot level data to understand the actual effect of flood hazard on farmers' livelihoods.

1. INTRODUCTION

Climate change is inevitable and impacts critical functions that are vulnerable to climate change, such as the agriculture and water sectors. Recent studies revealed that, due to climate change, the world is moving towards scenarios of either too much or too little water. Agriculture is an open system and provides livelihoods for 60% of the world's population. Eighty-six percent (86%) of production loss in Asia's agriculture sector is due to floods (FAO, 2017). More than 2.2 billion people depend on agriculture for their livelihoods in Asia (ADB, 2009). Thus, climate-induced natural hazards, especially floods, are likely to considerably affect the agriculture sector and the livelihoods of the dependent population.

Due to the distinct climatic variability across the Asian continent and its geophysical setting, most countries on the Asian continent are subject to natural disasters. The frequency of these extreme events, especially the hydro-meteorological events, has shown an increasing trend (Thomas & López, 2015). Amongst various hydro-meteorological hazards, flood hazards are one of the consequences of climate change-induced extreme events. Considering the effects of climate change-induced floods, South Asia is one of the world's most vulnerable regions to floods (Mirza, 2011). Floods frequently occur in these places, which were hit by higher monsoon precipitation levels. They can cause significant damages to animal and human lives, property, crops and infrastructure. The frequency, magnitude and extent of extreme floods have been increasing in South Asian countries. In the context of cropping patterns, Asia accounts for more than 80% of global rice production (Sekhar, 2018). Therefore, flooding during the monsoon season can cause major damage to crop yields, especially rice, which may have secondary implications on several socio-economic indicators, including food security of vulnerable groups and public health in the flood plains.

From a disaster management perspective post-disaster evaluation is carried out for damage and loss, while from a climate change adaptation perspective, evaluation or assessment is carried out of loss and damage. The basic difference between the two is the former looks into estimating the damage to economic and social infrastructure, human lives etc. (Mckenzie, Prasad, & Kaloumaira, 2005), focussing on the strategic impacts immediately after a disaster strikes, while the latter focusses on the potential of loss of economic flow and possible damage to life and property that may occur in areas vulnerable to disasters (OML Center, 2017) . In both cases, evaluation for the agriculture sector is very challenging. Damage in the agriculture sector accounts for the effects on standing crop, farm machinery, irrigation systems, livestock shelters, fishing vessels, pens and ponds and the economic cost to replace or repair. On the other hand, loss, is caused by changes in economic flow arising out of the decline in crop production, decline in income from livestock product, increase of input prices, reduction in overall agriculture revenue and unexpected immediate needs in post-disaster events (Conforti, Markova, & Tochkov, 2020). Most of the studies or methodology developed so far for the agriculture sector concentrates on post-disaster damage and loss evaluation. One of the recent FAO methodologies looks into damage and loss to production and damage to assets. However, it has some boundary conditions (Conforti et al., 2020) and applicable to post-disaster events. The methodology considers damage and loss to all the components of the agriculture landscape and looks into damage into annual and perennial crops. A number of other studies mainly carried out in Europe looked into damage functions for agriculture within the framework of an economic appraisal of flood management projects. However, the methods have concentrated mainly towards damage to crops and less towards assets (Brémond, Grelot, & Agenais, 2013). Some remote-based studies also evaluate post-disaster damage and loss to the agriculture sector (Torbick, Chowdhury, Salas, & Qi, 2017; Jin, Xiao, Dong, Qin, & Wang, 2015; Ahmed, Rahaman, Kok, & Hassan, 2017; Singha, Wu, & Zhang, 2016; Shrestha et al., 2017).

The present study aims to test the econometric methodology for estimating loss and damage due to floods in the agricultural sector to strengthen early warning systems for floods and improve the methodology for flood risk assessment considering climate change. The present study is part of research conducted in three countries in Asia, namely Sri Lanka, Nepal and Thailand. The paper presents the outcome of the study carried out in Sri Lanka. The key objective of this study is to investigate the effect of floods on agriculture production and how farmers cope with the losses caused by floods.

1.1. Study area background

Sri Lanka is an island located at the tip of the Indian sub-continent surrounded by the Indian Ocean. 77.4% of the Sri Lanka rural population of Sri Lanka depends on agriculture as their major livelihood option (Marambe, Silva, & Athauda, 2017) and are frequently hit by natural disasters. Sri Lanka has seen a steady rise in the frequency of floods over the past two decades (IWMI, 2018). Flood occurrence in Sri Lanka is almost regular in the recent decade (every year over the last ten years), with an apparent increase in the affected areas. Based on observation, on average, fewer than five districts were affected by floods during the period 1991 to 2000, which doubles in the last decade. Studies on the effect of floods on agricultural production in Sri Lanka is limited. Thus, understanding the effect of floods on agricultural production and how farmers respond to the losses caused by floods is vital for policy-makers and government institutions. The uniqueness of the present study is that it utilizes natural field experiment data at a micro-plot level that is less likely to be disturbed by other factors, allowing identification of the hazard's actual effect on the farmers' livelihood.

2. METHODOLOGY

2.1. Flood hazard zonation

To develop a comprehensive flood model, accurate topographic data with all land use, elevations, stream cross-sections, dimensions, and stream network levels are necessary. However, during data collection, it was found that most of the required data set was not available. Thus, instead of a flood hazard mapping of the individual districts, we considered the plot-wise water level to measure severity. For the study, we employed a water surface elevation calculation method recommended by FEMA (2018). This method calculates flood-water height at a resolution of 0.0002 arc degrees (i.e. around 22 meters) using earth surface elevation data sourced from ASTER Global Digital Elevation Model Version 2 (GDEM v2) and the flood inundation extent map available from the Disaster Management Centre, Government of Sri Lanka.

2.2. Future precipitation projection

Future climate change scenarios can play a vital role in preventing and mitigating hydro-meteorological disasters (Islam, Rafiuddin, Ahmed, & Kolli, 2008). The data generated by climate models can be used as inputs for a number of physical, hydrological and agricultural models to predict future climate change impacts. Using these models, policy-makers can better develop evidence-based and rigorous strategies and reduce the impact of these disasters on communities Stainforth, Downing, Washington, Lopez, and New (2007).

A thorough review was conducted to acquire future climate change data with an acceptable horizontal resolution to analyze future precipitation projection of Sri Lanka. NASA Earth Exchange (NEX) models, which have future climate change scenarios from 21 Global Circulation Models (GMCs) under two emission scenarios (RCP 4.5 and 8.5) with 25 x 25 km^2 resolution were identified. The NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset comprised of downscaled climate scenarios for the globe were derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Inter-comparison Project Phase 5 (CMIP5) (Taylor, Stouffer, & Meehl, 2012) and across two of the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs) (Meinshausen et al., 2011). Out of the NASA Earth Exchange (NEX) 21 models (CMIP5 models) with RCP4.5 and RCP8.5 emission scenarios, 12 GCMs were found to be suitable for understanding future change of annual mean temperature (ΔT) and percentage (%) chance of annual precipitation ($\Delta P\%$) over South Asia and especially Sri Lanka. As the present study dealt with flood, identifying extreme wettest events in the future was important. The models closest to the 10th and 90th percentile of the change of annual mean temperature (ΔT) and % change of annual precipitation ($\Delta P\%$) during the 2030s, 2050s and 2080s in the two RCPs were considered for the study as they represent extreme conditions. The plots of projected changes in annual average temperature and precipitation by 2080 are given in Figure 1.

A similar analysis to identify the suitable model depicting the wettest/ hottest extreme for the northeast monsoon season and south-west monsoon season for 2080 time period as well annual, south-west monsoon season and north-east monsoon season for 2030 and 2050 time period was carried out. The three-time periods' analysis results identified that the CSIRO-Mk3-6-0 model shows extreme conditions (wettest/hottest) over Sri Lanka during all time horizons with RCP4.5 and RCP8.5 scenarios.

2.3. Pilot site selection

A standard randomized sampling technique developed by Deakin University in Australia was employed to select the pilot sites, including flood-affected areas (treatment site) and non-flood affected areas (control site). The project team used an experimental design to conduct the two surveys: one baseline survey and another endline survey in areas affected by climate-induced floods (treatment site) and non-affected areas (control site). Based on historical climate information, the project team identified climate-induced flood hazard regions termed as 'treatment areas' and the other part of the country as 'comparison areas'. Sri Lanka has 25 districts in total, which can be categorized into three zones: wet, intermediate, and dry regions. Based on the previous 25 years of flood history, districts are divided into more-likely-affected-group, which comprise those with more than four years of flood incidents and the other group, namely less-likely-affected-group for the districts with less than four years of flood experience. Based on this categorization, 11 districts fall into the affected group leaving 14 remaining districts in the non-affected group. The research design randomly chose two potential treatment districts from the affected group and two control districts from the non-affected group. The two districts selected for the affected group were from the wet zone as all the 11 affected districts were from the wet zone, while the two districts selected from the control group was one from the wet zone and one from the intermediate zone as the 14 unaffected districts were from all the three zones. The districts from the dry zone were not considered as they had an ancient irrigation system in place to compensate for rainfall deficit. All four districts thus had only

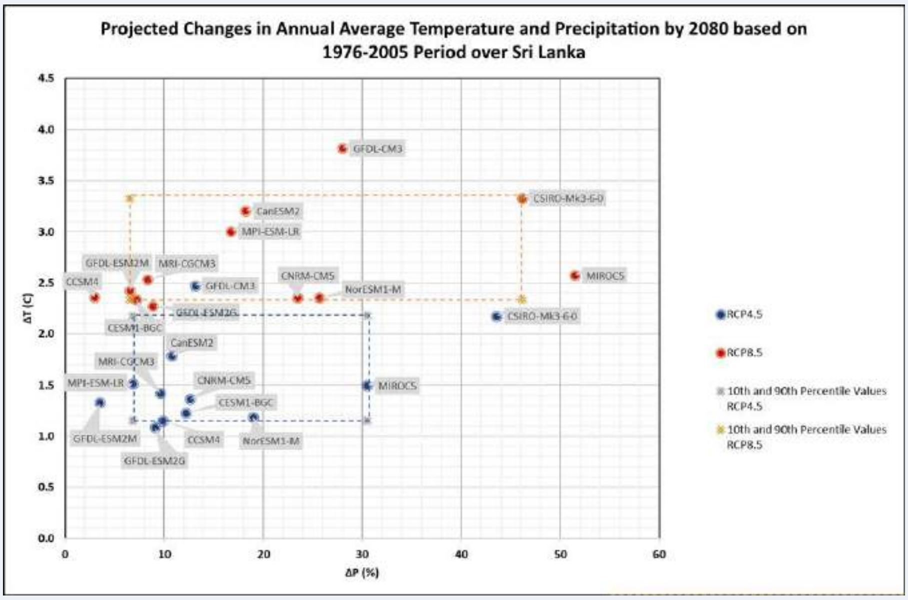

FIGURE 1. Identification of model depicting the extreme projected annual average temperature and precipitation by 2080 over Sri Lanka (10th and 90th percentile).

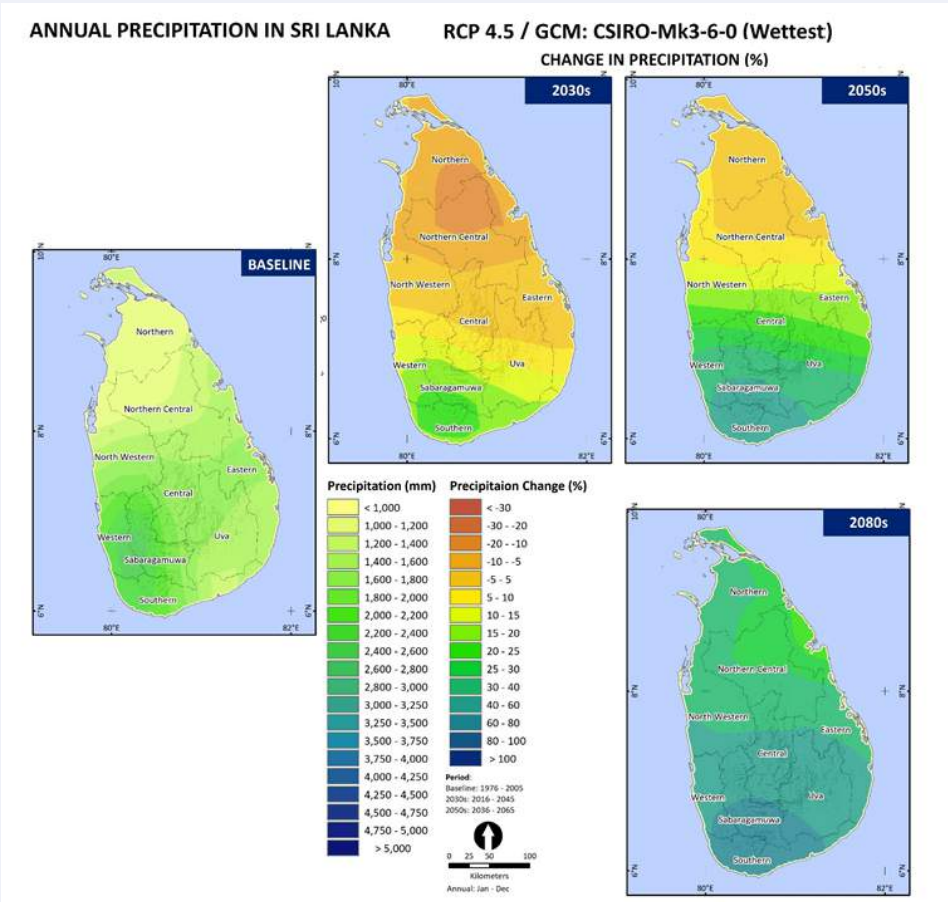

FIGURE 2. Projected Change in annual average precipitation over Sri Lanka for 2030, 2050 and 2080 time period derived from CSIRO-Mk3-6-0 for the RCP4.5 scenario.

rainfall dependency for agriculture.

The unit of areas was defined at the polygon level and spatially clustered based on its potential for paddy crop arability along with its level of climate-induced flood hazard risks. The general delineation of polygons into treated and control cohorts was also identified in a similar way. In particular, the following steps were taken in identifying the study area:

1. Collecting district level historical flood data (affected area and timeline of flood events, number of casualties, and damage and losses);
2. Selecting four districts in each country and dividing all of the four districts into two groups: experiencing floods (treated districts) and never exposed to floods (control districts);
3. Collecting the land use/landcover data in GIS format (shapefiles) that includes information such as arable/farmland, type of crops cultivated in each unit of land, etc.
4. Overlaying district administrative boundary on the land use map;
5. Within the list of treated districts (referring to selection criterion 2) in the zone, two districts were picked randomly;
6. For each of the two districts selected as per criterion 5, it was ensured that:
   (a) The number of rice plots is equal;
   (b) Those rice plots' total area should sum up to a similar figure even though there could be variations.
7. Information was also collected on the characteristics for each of the randomly selected rice plots in criterion 6 on the size of cultivated land, proximity to water body, forest land, elevation/ruggedness, rainfall and temperature statistics, socio-economic status of the households, and on the whole, paddy-related data.

Another two districts were also randomly selected as control districts to meet the criteria as mentioned below:

1. Two districts were selected as non-flooded districts (control);
2. The selection of the rice plots should be such that they resemble approximately the size of the treatment plots;
3. The number of selected rice plots for treatment and control is kept equal and considers the geographic, topographic, demographic, economic, and socio-economic attributes the same for all the districts.

Based on the above, 125 rice plots were considered from each district randomly covering both control and treatment groups. Two surveys were carried out (baseline survey and end-line survey) between 2016 and 2017. Based on the number of plots affected, the treatment group included 251 plots affected by floods, while the control group comprised 697 plots that were not affected by floods in any of the two years. Galle and Gampaha were the two affected districts, while Kegalle and Monaragala were the two unaffected districts (Figure 3).

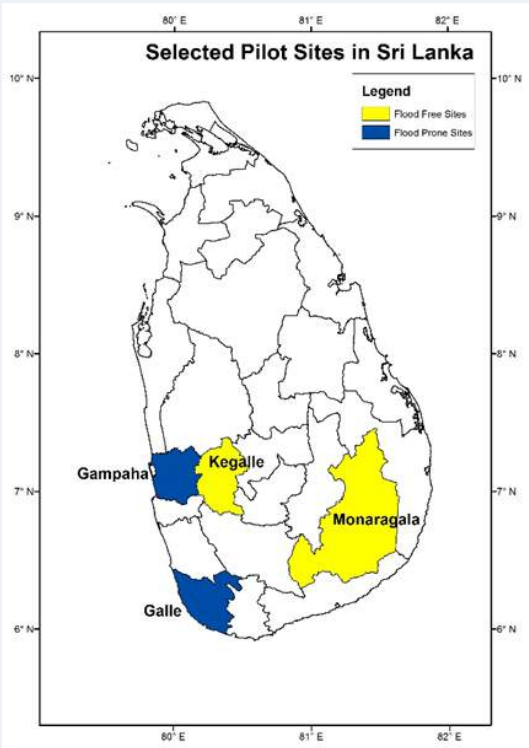

FIGURE 3. Maps showing the pilot sites in Sri Lanka.

2.4. Econometric model on loss and damage in the agriculture sector

The econometric model used difference-in-difference (DD) framework (Ashenfelter & Card, 1985; Bertrand, Duflo, & Mullainathan, 2004; Wing, Simon, & Bello-Gomez, 2018) to evaluate the effect of the flood on crop production (Merz, Kreibich, Schwarze, & Thieken, 2010). The DD framework compares the average changes in the outcome variables for the treatment group and the control group before and after flood. The Standard DD equation is as follows:

$$Y_{it} = \alpha Treatment_{it} + \beta After_t + \gamma Treatment_{it} After_t + \epsilon_{it} \quad (1)$$

where subscript i indicates individual (household/-plot) and subscript t denotes year. Y_{it} is the outcome of interest of individual i at time t. Our primary outcomes of interest include crop production indicators: crop yield, crop output, and crop area. $Treatment_{it}$ is an indicator equal to 1 for individuals that belong to the treatment group in year t and 0 otherwise. $After_t$ is an indicator for timing of the treatment, β is the difference in the outcome between the two periods, before and after floods, the coefficient of interaction between these two variables ($Treatment_{it}$ and $After_t$), γ, measures the effect of floods and ϵ_{it} is a composite measurement error. As districts were chosen randomly, it is likely that several indicators such as paddy yield or coverage area significantly differ between treatment and control plots before floods. To reduce the bias, district fixed effect was introduced in the model modifying the Standard DD equation

$$Y_{it} = a_d + \alpha Treatment_{it} + \beta After_t + \gamma Treatment_{it} After_t + \epsilon_{it} \quad (2)$$

where a_d is the district fixed effect. Similarly, we incorporate covariates representing household/plot characteristics and inputs for production function into the model by considering the farmer's reaction to flood where they may adjust the production inputs to offset the negative effect of floods. Thus, the equation was modified to

$$Y_{it} = a_d + \alpha Treatment_{it} + \beta After_t + \gamma Treatment_{it} After_t + Z_{it} + \epsilon_{it} \quad (3)$$

where Z_{it} is a set of household/plot characteristics and inputs that are appropriate for each of the outcomes. Thus, for the yield equation, we controlled the household's endowment, including total land area owned (in log), household size (total household members), crop cultivation period (in months), and fertilizer use (in log). Crop cultivated area is an additional control when the outcome is crop output. For the outcome being crop area, crop output (in log) is added along with the set of controls in the yield equation. A variation of equation 3 is also used when we include flood fixed effect in the model whenever the coefficient of flood-water height or log (flood-water height) is statistically different from zero, suggesting that the two groups are permanently different. The coefficient with flood fixed effect is as follows:

$$Y_{it} = a_d + b_f + \alpha Treatment_{it} + \beta After_t + \gamma Treatment_{it} After_t + Z_{it} + \epsilon_{it} \quad (3')$$

where b_f is the coefficient with flood fixed effect. Finally, standard errors are clustered at the household/plot level in our estimation.

3. RESULTS AND DISCUSSION

A number of components were considered for the present study. The flood inundation extent and flood height were measured for each plot using the flood extent map available from the Sri Lankan Disaster Management Department and ASTER GDEM v2. Historical climate data analysis enabled us to select the pilot districts (treatment and control) in the three zones. The future precipitation projection using the NEX-GDDP model shows that these areas are likely to be affected in the future. Thus, the econometric model tested in the project area can effectively be used to estimate loss and damage.

A number of scenarios were considered for loss and damage assessment using the econometric model. The descriptive statistics and the changes in households/plots' characteristics before and after the flood hazard for treatment plots and control plots are given in Table 1 . Farmers were grouped into two (a) group averse to risk-taking and (b) farmers who show a willingness to take risk.

	Treatment plots			Control plots			Treatment-control
	Before (2015)	After (2017)	Differences (2)-(1)	Before (2015)	After (2017)	Differences (5)-(4)	Before (1)-(4)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Whole sample							
Demographic characteristics:							
Household size	4.29	4.31	0.02	4.41	4.45	0.04	-0.12
Household head age	54.51	56.77	2.26	55.78	57.77	1.99**	-1.27
Number of males in household	2.08	2.07	-0.01	2.23	2.26	0.03	-0.15
Household members aged 50+	1.75	1.73	-0.02	1.75	1.73	-0.02	0
Literate	1.00	1.00	0	1.00	1.00	0	0
Economic characteristics:							
Land area own (m^2)	8960.80	8677.38	-283.42	7949.55	8496.24	546.69	1011.25
Weekly income (USD)	48.23	51.07	2.84	49.48	49.45	-0.03	-1.25
Agriculture-related characteristics:							
Paddy production (m^2)	2443.82	2299.69	-144.13	2748.64	2876.45	127.81	- 304.82
Paddy production area (m^2)	6881.7	7071.4	189.7	5770	6576.6	806.6	1111.70
Paddy yield (kg/m^2)	0.37	0.34	-0.03	0.55	0.54	-0.01	- 0.18***
Non-paddy production (kg/m^2)	4540.47	5514.93	974.46	4044.69	4994.54	949.85	495.78
Non-paddy production area (m^2)	3524.88	5600.78	2075.9	5803.17	6300.60	497.43	- 2278.29
Non-paddy yield (kg/m^2)	1.89	0.99	-0.9	1.84	1.84	0	0.05
Cultivation duration (month)	7.10	7.12	0.02	7.33	6.79	-0.54	- 0.23
Volume of fertilizer (kg)	632.57	791.80	159.23	558.32	754.42	196.1	74.25
Number of crops produced (kg)	1.31	1.40	0.09	1.36	1.25	-0.11***	- 0.05
Behavioural characteristics:							
Willingness to take risk	5.82	5.98	0.16	7.23	7.03	-0.2	-1.41***
Flood-related characteristics:							
Flood exposure dummy	1.00	1.00					
Flood water height in plots (m^2)	3.69	4.35***					
Panel B: For DD Equation – Averse to risk-taking sample							
Paddy production (kg/m^2)	2142.40	1694.70	-447.70	1498.30	1865.10	366.80	644.10
Paddy production area (m^2)	6964.50	5342.80	-1621.70	4118.40	4244	125.60	2846.10***

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Table 1 continued

Paddy yield (kg/m²)	0.326	0.331	0.005	0.432	0.455	0.023	-0.106***
Non-paddy production (kg/m²)	3441.75	2739.12	-702.63	2637.29	3135.41	498.12	306.34
Non-paddy production area (m²)	3598.86	4079.78	480.92	4092.60	3801.76	-290.84	-202.90
Non-paddy yield (kg/m²)	1.09	0.58	-0.51	1.33	2.29	0.96	-1.20
Flood water height in plots (m)	3.58	4.28***					
Panel C: For DD Equation - Willing to take risk sample							
Paddy production (kg/m²)	2865.80	2711.40	-154.40	2995.90	3063.90	68	-130.10
Paddy production area (m²)	6765.80	8247.90	1482.10	6096.80	7009	912.20	669
Paddy yield (kg/m²)	0.441	0.343	-0.098***	0.573	0.558	-0.015	-0.132**
Non-paddy production (kg/m²)	5686.96	7262.67	1575.71	4256.56	5357.82	1101.26	1430.40
Non-paddy production area (m²)	3447.69	6614.78	3167.09	6055.25	6772.60	717.35	-2607.56
Non-paddy yield (kg/m²)	2.73	1.26	-1.47	1.92	1.75	-0.17	0.81
Flood water height in plots (m)	3.82	4.39**					

TABLE 1. Descriptive statistics of treatment plots and control plots.

Notes: Panel A shows the average characteristics and the change in the mean value of the treatment and control households before and after the flood (the baseline survey was conducted just before the 2016 flood while the end line survey collected data of the same plots/households one year after flood occurrence). It also provides the differences before the flood strikes for treatment and control plots (column (7)). Household size is the number of household members; literacy variable equals 1 if the household head is literate and zero otherwise. Panel B and C shows statistics of paddy and non-paddy production variables before and after a flood for two sub-samples, risk-taker vs. risk-averse groups. Panel B is the treatment group comprises of flood-affected plots with households' willingness-to-take-risk at least 6 (risk-taker) while the control group includes those not affected by floods and are risk-taker. Panel C is the treatment group of farmers who are flood-affected and are risk-averse (willingness-to-take-risk is below 6). Non-affected farmers with willingness-to-take-risk less than 6 make up the control group in this case. Statistical differences are marked as '*' (*p<0.1, **p<0.05, ***p<0.01).

3.1. Effect of the flood on paddy yield (whole sample

The first model run was for the entire sample, including both groups. The first regression in each block (corresponding to Equation (1)) controls for only flood shock variables. In the second regression of each block (corresponding to Equation (2)), district fixed effect is added to eliminate the variation from permanent differences between control and treatment districts that may bias the estimate. The third regression in each block (corresponding to Equation (3)) includes a set of household characteristics and paddy production inputs. It is important to highlight that since the district fixed effect is controlled for all three blocks, there is no difference between the control and treatment groups. It was found that on average if all else is equal, 1 meter of flood-water height in plots causes 2.2% yield loss which is equivalent to a loss of 44,220 kg paddy output for 1 km^2 of paddy production area (see Table 2).

3.2. Effect of flood on non-paddy yield

When considering the effect on non-paddy yield, the two groups were considered separately. It was observed that a considerable loss of non-paddy yield of about 84% for farmers averse to risk-taking using our preferred measure of floods (flood-water height in plots). The estimate of yield loss is significant at 5% level for all three flood measures. On the other hand, the loss is around half for the farmers willing to take the risk though yield loss estimate is not significant for all three flood measures. Thus, it can be inferred from our results that farmers who are averse to risk-taking give priority to paddy while cultivating non-paddy crops on riskier plots. Hence, they can avoid yield loss for paddy, which comes at the expense of a large loss for non-paddy crops. On the other hand, farmers willing to take a risk tend to be more open to growing non-paddy crops in less risky plots and paddy crops in riskier plots.

3.3. Effect of flood on paddy and non-paddy production

The study also looked into the production of paddy and non-paddy crop besides the yield. It was found that if the estimate includes all the three conditions, district fixed effect, household characteristics and production inputs and effect of the flood on crop output is evaluated with the assumption that crop production area is kept the same as without flood incidents. The effect of the flood on production output is very similar to the effect on yield function. Flood has a negative and significant effect on both paddy output and non-paddy output in the whole sample. While considering farmers averse to risk-taking, there is no effect on paddy output while it is huge for non-paddy output. In contrast, for farmers willing to take a risk, a large and significant adverse effect on paddy output is observed, while the effect on non-paddy output is large though insignificant.

The present study shows that the flood causes output loss for both paddy and non-paddy crops. Farmers who are reluctant to take risk shoulder the loss of both paddy and non-paddy crop production, while farmers willing to take risk incur the loss of paddy production. They all respond to the loss by expanding production area, with the former pursuing non-paddy production while the latter favouring paddy crop production. On the one hand, though post-flood high soil moisture content is a good pre-condition for cultivating crops, the risk of pest, diseases, and crop failure is more likely to occur due to changes in soil biotic conditions caused by the flood.

Post-disaster damage and loss evaluation is generally carried out using remote sensing data due to wide coverage and shorter temporal resolution. Still, the data used in the studies so far are mainly RADAR data or MODIS Data or Landsat data, which have a very coarse resolution. As a result, the damage and loss can be analyzed up to a certain scale. On the other hand, review of a number of other studies on flood damage to agriculture showed that damage and loss assessments have been carried

Flood measures	I: Flood dummies			II: Flood-water height in plots		
Equations	(1)	(2)	(3)	(1)	(2)	(3)
Flood dummy	-0.33***	0.056	0.053			
	(5.81)	(0.84)	(0.80)			
After	-0.023	0.031	0.046	-0.024	0.025	0.038
	(0.67)	(0.93)	(1.47)	(0.74)	(0.77)	(1.23)
Flood dummy × After	-0.035	-0.092*	-0.13**			
	(0.70)	(1.84)	(2.50)			
Paddy cultivation duration			0.021			0.021
			(1.64)			(1.63)
Log (Fertilizer use)			0.065**			0.066**
			(2.22)			(2.23)
Log (Land area owned)			-0.16***			-0.17***
			(5.03)			(5.08)
Household size			-0.026			-0.027
			(1.49)			(1.55)
Flood-water height				-0.085***	-0.00085	-0.0023
				(6.05)	(0.05)	(0.15)
Flood-water height × After				0.0063	-0.016	-0.022*
				(0.52)	(1.28)	(1.75)
r^2	0.069	0.22	0.27	0.070	0.22	0.27
N	863	863	796	863	863	796
Equation includes						
District Fixed Effect	No	Yes	Yes	No	Yes	Yes
Plot Level Controls	No	No	Yes	No	No	Yes

Notes: This table reports regression result with outcome being log of paddy yield using a different set of controls for each of the flood measures. In the first column of each block, only flood-related variables are controlled. The second column adds a district fixed effect, while the last column incorporates a set of household characteristics and paddy production inputs. Standard error is clustered at the plot level. T-statistics is in parenthesis. Statistical differences are marked as '*'(*p<0.1, **p<0.05, ***p<0.01).

TABLE 2. Effect of floods on paddy yield

out to evaluate direct instantaneous, direct induced and indirect damage to agriculture (Brémond et al., 2013). The analysis of studies by Brémond et al. (2013) found that damage function of crops need to be improved and vegetative growth stage of crops require consideration as damage to crops and resulting loss are likely to be different at different stages thus influencing the crop damage function. The present methodology is not applicable for post-disaster damage and loss. Rather, it estimates the potential loss and likely damage in the future based on past events. The loss and damage assessment carried out in the present study also took a hybrid approach where flood inundation has been analyzed from satellite sensor data (SRTM), but the potential loss and damage assessment was carried out at the household level based on the exposure of the plot owned by the farmer to flood. The present study is a panel-based statistical approach where the challenge of unobserved omitted variables in identifying a causative relationship between natural disasters and agricultural outcomes are taken care of by using a panel-based dataset. As the data used is at the micro-plot level, it is less likely to be disturbed by other factors allowing for the identification of the true effect of flood damage on production. The present study also looked at the farmers' behavioural and demographic characteristics as part of the panel data set, which has not been considered in other studies. Uncertainty is an integral part of any model technique. In the DD Framework, the major source of uncertainty is sampling error. The standard randomized sample technique was thus used to reduce the uncertainty in sampling. Additionally, the current study did not consider other agriculture components except the

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paddy and non-paddy crops.

4. CONCLUSION

Agriculture production largely depends on the weather condition and is extremely prone to natural disasters and hazards. A more frequent and severe occurrence of natural disasters such as storms and floods in recent decades has put food security at an increased risk and undermine farmers' life satisfaction. Farmers in less developed countries are most vulnerable to natural disasters and hazards due to lack of support from the government and limited resources to overcome the losses. Sri Lanka, a developing country with the majority of the rural population (77.4%) dependent on agriculture, is hit by annual flood with an increase in the affected area in the recent decade. This study investigates the effect of floods on agriculture production and farmers' response to flood incident using data at the plot level. Our research design applies the removal of potential bias caused by the difference between treatment and control group at the district level, generated a sample equivalent to that from a randomized control trial. This allows us to quantify the causal effect of floods using the DD framework. The research concluded the following: 1) The estimate shows a significant loss in paddy yield of 44,000 kg/km^2 owning to floods in the studied years; 2) the farmers who are averse to risk-taking give priority to paddy while cultivating non-paddy crops on riskier plots; and 3) in contrast, farmers willing to take a risk, tend to be more open to growing non-paddy crops in less risky plots.

Farmers offset this loss by expanding crop cultivated area utilizing the soaked field after the flood though there are chances of pest attack and disease. The study also shows that historical climate information, plot-level flood-water height estimation using GDEM v2, and flood extent information can be useful as an input to the econometric model to estimate potential loss and damage. The study opens an opportunity for future research on the usage of future precipitation projection information in estimating future floods and using the information to estimate likely loss and damage to enable better adaptation and mitigation measures as well as include other components of the agriculture sector such as livestock, fisheries, etc. As the present model is robust enough to different flood incident measures/intensity, it may also be tested in other flood-prone agriculture dominant economies.

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Review

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Venturing sustainability: Political lessons from civic engagement and transformative learning in Asia

Maharani Hapsari [a,*], **Dicky Sofjan** [b], **Theodore Mayer** [c]

[a] Department of International Relations, Faculty of Social and Political Science, Universitas Gadjah Mada, Yogyakarta, Indonesia

[b] Indonesian Consortium for Religious Studies (ICRS), Universitas Gadjah Mada, Yogyakarta, Indonesia

[c] School of English for Engaged Social Services (SENS), Institute for Transformative Learning of the International Network of Engaged Buddhism (INEB Institute), Bangkok, Thailand

* *Corresponding author. Email: ranihps@ugm.ac.id.*

ABSTRACT

Current studies on civic engagement offer a critical examination of global civil society's struggles for a sustainable future. The liberal conception of civic engagement sees citizens as voluntary and participatory political subjects in their capacity to achieve a sustainability agenda. In Asia, such conceptions meet with the complex nature of power relations. Using a Gramscian approach and interpretive analysis, this paper draws on the struggles for hegemony, where power relations manifest subtly in state policy, market economy and civil society domains. Learning from the transformative learning experiences of various civil society actors, this study argues that in Asian realities, civic engagement is deeply concerned with the underlying structure of power, forms of negotiation and power dynamics. Political asymmetry is often made implicit by the privileged or uncritically internalized in civic life. There is a need to examine civic engagement as part of "the political", in which antagonism and contradiction are constitutive to social change. Furthermore, civic engagement can, and does, stimulate citizens' deliberate and concerted action against inequality, injustice and indignity.

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KEYWORDS

Civic engagement, transformative learning, sustainability, civil society, Asia, hegemony

HIGHLIGHTS

- Transformative learning as a mode of civic engagement is gaining importance in understanding the trajectory of global sustainability transformation.
- The experience of civil society actors in Asia suggests a deeper reflection on the prospect of advancing civic engagement in the struggle for collective will and political leadership.
- Civic engagement involves political struggle to transform power structures that are formative to cultural hegemony.
- Advancing the transformative impacts of civic engagement could address the roots of political exclusions that impede the individual agency.

1. INTRODUCTION

The importance of civic engagement as a feature of liberal democratic societies has been well recognized and documented since the initial work of 19th-century British philosopher and political theorist John Stuart Mill's "civic liberalism" (Miller, 2000). Civic engagement includes community service, collective action and political involvement, which are seen in transformative terms since the practices are oriented toward social change (Adler & Goggin, 2005). It is noteworthy to learn how Asian societies encounter civic engagement as an open democratic project within their unique socio-economic and cultural context. In pursuing a sustainable future, civic engagement brings together various nationalities, identities, affiliations, and roles of citizens in articulating democratic values and civic cultures as transformative forces. With its long history of communitarian and Confucian traditions, the Asian trajectory of social transformation does not always conform with liberal democratic culture (Hood, 1998). Asia is also home to growth-oriented development models and emerging sustainability technology initiatives. As a site of political struggles by unprivileged individuals and groups, it is a fertile ground for civic engagement and transformative learning projects as politically constituted practices. Critical evaluation of civic engagement in Asia calls for a re-interpretation of being a citizen as part of the larger governing whole. Sustainability desires a systemic transformation to alter the anthropocentric paradigm that drives current planetary metabolism toward a more desirable future that balances intra- and inter-generational justice (WCED, 1987).

Examining civic engagement as part of "the political" (Mouffe, 2005), this paper arises from the dissemination of an international collaborative project that resulted in an edited volume entitled Civic Engagement in Asia: Lessons from Transformative Learning in the Quest for a Sustainable Future (Indrawan, Luzar, Hanna, & Mayer, 2020). With 24 scholarly works representing civic initiatives from various disciplines, professions, and nationalities, the volume documents how civil society actors working in Asian countries address existential dilemmas while challenging their deeply held assumptions and perspectives in relation to the social world at its broadest through various modes of transformative learning (Mezirow, 1991).

This paper uses Gramscian analysis on civic engagement as a political project in which the struggle for hegemony is integral to social transformation (Gramsci, 1971). Data is sourced from selected chapters in the edited volume, representing cases in Indonesia, Vietnam, Thailand,

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the Philippines and Pakistan. These cases cover the experiences of indigenous people, farmers, workers, local communities, women, teachers, students and religious communities involved in multi-year collaborative knowledge production and civic activisms. The scope of sustainability areas includes human trafficking, urban planning and development, indigenous people's rights, sustainable forestry and sustainable agriculture, social and religious harmony, capacity building and networking support for civil society groups, knowledge creation and sharing, and leadership sharing (Vannarith, Yin, & Mayer, 2020). Through interpretive analysis, this paper shows how civic engagement practices and transformative learning develop in three domains of hegemonic struggles, namely state policy, the market economy and civil society. It unpacks the structural and cultural context of power imbalances as civil society actors seek to transform inequality, injustices, and indignity that hamper future sustainability. It also presents crucial political issues regarding the everyday and systemic changes towards a collectively desirable sustainability path.

2. TRANSFORMATIVE LEARNING AS A HEGEMONIC PROJECT

The term transformative learning was introduced by Jack Mezirow (Mezirow, 1978) within the field of education studies and is widely adopted by scholars in various other disciplines. The concept helps to unmask the struggles of unprivileged individuals and social groups when coping with various forms of oppression associated with their everyday social, economic and political dimensions (Schugurensky, 2002). It emphasizes the importance of critical thinking in nurturing individual consciousness, individual behaviour and social transformation against the backdrop of structural and cultural constraints. Therefore, the aspect of self-transformation is as fundamental as realizing the vision to change the social system.

This paper examines transformative learning within the broad constitution of "the political" (Mouffe, 2005) and the contestation of hegemonic leadership (Gramsci, 1971; Thomas, 2009). Hegemony is concerned with how the superstructural elements of civic life—among others, transcendental values, ideology, knowledge production and policy frameworks, along with the expectations of being good citizens—are rationalized. Institutional reforms at the local, national and regional levels signify the response to contradictions that are integral to social change. "The political" denotes the presence of antagonism in the society, whereby differences and conflicts of interest commonly centre on a few dominant groups. The inclusion and exclusion of citizens' antagonism play an important role in shaping the conditions for everyday political contestation. Power relations arrest and constrain antagonism and contradiction to create some form of temporal stability. In such a context, civic engagement can be understood as a way to transform contradictions and antagonisms in society through the discovery of a collective will that is based on a particular ideological leadership and political constellation. In this process, no particular outcome is assured. Rather, sustainability as a focus of civic engagement is ventured, put to the test, set in motion to encounter and work with these myriad contradictions and antagonisms.

The Asian experience presents the dynamics of hegemonic struggles in three domains, namely state policy, the market economy and civil society. In the state domain, transformative learning faces the sedimentation of technical rationalities that often separate bureaucratic or technocratic experts from the rest, which is the case in urban reform in Indonesia (Rifai, 2020). Elite culture defines the distribution of political authority and its privileged knowledge and legitimizes the work of public institutions. The experience of indigenous ethnic communities in Vietnam, the Philippines and Indonesia in reclaiming their rights to land-based livelihoods (Lanh, 2020; Royo, Praputra, Jamisolamin, & Rochaeni, 2020) discloses continuous negotiation of farmers and agrarian communities with privileged political actors in land-use governance. When political accountability is lacking, policy failures and corruption exacerbate unequal redistribution of opportunities at the expense of the non-privileged actors. Policy authority is often associated with dominant interest groups who have the power to counter dissent and critics before they surface. The experience of policy entrepreneurs in Malaysia in mainstreaming conservation policy shows that the scarcity of political resources and the limited space to accommodate a critical stance on government policies leads to self-censorship among civil society actors (Hezri, 2020). In such settings, civic engagement may emerge as a top-down process in which citizens are invited to participate in formulating and implementing government policies. This often relies on leading figures having political openness to embrace diverse civil society aspirations, including those coming from the opposition.

In the market economy domain, the excessive impacts of global capitalism drive various sustainability initiatives. The economic restructuring of local livelihoods needs to take into account two political-economic challenges. The first one is poverty. The case of dealing with human trafficking shows how economically marginalized people are pushed toward risking their lives as they struggle to secure access to the labour market and wealth redistribution beyond national borders (Srakaew & Tungpuchayakul, 2020). The multiple constraints that overlay the struggle for basic livelihoods often make inclusive public aspirations difficult to realize. The second one is the international pressure toward an autonomous market. In a globalizing economy, market disciplines are strong drivers of shifting citizens' mentality toward becoming economically competitive subjects. Such market disciplines often create pressures on the government to reconcile labour protections and environmental standards with market opening and liberalization. In Thailand, citizen science that works through community monitoring supports pollution-affected communities in industrial sites. This signifies a collective will to limit market externalities that jeopardize the quality of life (Saetang, 2020). Re-embedding social control allows citizens to reclaim the public sphere amidst the infinite pressure of economic growth.

In the civic domain, the mobilization of collective action at the grassroots is a central aspect of transformative learning, one that also represents a critique of the predominant top-down approaches. Such mobilization mostly relies on the power of networked actions, which are fluid in nature. This is also intertwined with the remaking of individual identities. Women's multiple roles as environmental professionals, home managers, policymakers, green entrepreneurs and educators shape the paths toward their environmental leadership in Pakistan when dealing with the climate crisis (Riaz & Dupar, 2020).

The Asian experience shows that transformative learning transcends the boundaries of territorial sovereignties. The roles of transnational civil society actors in facilitating knowledge production across civic networks are crucial in amplifying the impacts of local struggles. The development of SENS (School of English for Engaged Social Service) by the Bangkok-based International Network of Engaged Buddhists (INEB) shows how such a program can be a site to cultivate human-nature reconnections while also being a cultural bridge to plural civilizations. Through a complex approach, including multiple intelligences, the classroom processes strengthen participants' confidence to unpack the oppressive structures in society that impede their transformative potential (Mayer, 2020). In the civic domain, the role of donor organizations as the interlocutors of knowledge production sites and as players in various aspects of global resource circulation is also well-acknowledged.

Currently, community empowerment and entrepreneurship programs are driven by international development donors, which frequently have to deal with the recurrent problem of economic dependence, which contradicts the normative directions. This is particularly true when the sustainability of these programs is not taken seriously into account in ensuring their long-term outcomes (Lanh, 2020). Furthermore, the asymmetric power between donor and beneficiary communities often makes the viewpoints of program beneficiaries less than fully articulated in the decision-making processes.

3. REIMAGINING CIVIC ENGAGEMENT: THE WAY FORWARD

The political ecosystem of transformative learning in Asia presents some unique structural constraints to substantive participation and articulation of civil society participation in advancing sustainability agendas. Structural constraints take the form of subtle power mechanisms, which are mostly implicit and are sustained through social inter-subjectivity among actors. Hegemony is embedded in various forms of cultural predominance exacerbated by socio-economic inequalities. The superiority of policymakers, knowledge experts, donors and cultural leaders throughout the process of knowledge production and circulation of resources in the civic networks often legitimizes power disparity through various superstructural means.

Civil society efforts are currently directed toward deepening the impacts of civic engagement projects through transformative actions. The sedimentation of soft politics is becoming a more salient aspect of civil society struggles to challenge inequality, injustice and indignity. Conscious everyday struggles in the form of "infrapolitics" (Scott, 1985) play a strategic role in the Asian context where harmony and cultural prudence have a deep influence on maintaining political obedience and policy compliance. Furthermore, civic-driven sustainability transformation relies heavily on strategies that put forward dialogue, persuasion and empowerment rather than the use of coercive power instruments.

There is a need to re-interpret the meaning of grassroots empowerment, public interchange, partnership and capacity building as prominent instruments of civic engagement. Embracing political realities in the Asian context requires civil society actors to be critical of the potential consequences of power asymmetries in their everyday and normalized forms. An alternative to relations of dominance, civic engagement strategies must be directed to strengthening the political agency of individuals. This is normatively conducted through negotiating what constitutes sustainability agendas that embrace broad-based socio-cultural representations. The entanglement of various sources of knowledge and wisdom presents both opportunity and challenges for civil society actors. Both internal and external critics in transformative learning continuously reshape individual subjectivities and identities. In the context of ecological sustainability, hegemonic struggles need to engage with the "hardware" (the scientific study of ecology and the use of technology), "software" (laws, regulations and policy frameworks imposed by authorities) and "heartware" (individuated, non-tangible and inner dimensions of the drivers of sustainability that are based on the sense of spiritual interconnectedness and a heightened awareness of the role of human beings as "stewards of the earth") (Sofjan, 2020).

More attention needs to be given to the everyday power negotiation through which civil society actors exert their influence and permeate the membranes of hegemonic political institutions. In this context, the intimate connections between civic engagement and citizenship deserve further exploration. Citizenship is concerned with the participation and recognition of citizens as political subjects and their active struggles against injustices within a larger structural context (Hiariej & Stokke, 2017). The questions of power in the three domains of "the political" provide the momentum for civil society actors to advance their political leverage. Against the backdrop of power disparities, collective actions have developed from the level of the personal to the institutional to the political. Beyond incentive-driven political pragmatism and genuine engagement by respective leaders, more political efforts to transform the subtle dimensions of power are worth exploring. Political change is desirable with the presence of broad-based political leadership that is able to glue the very diverse political positions and nurture cross-sector alliances.

4. CONCLUSIONS

The Asian experience with transformative learning and civic engagement projects provides some important political lessons to further the transition to sustainability. It highlights hegemonic struggles in selected Asian countries and selected sectors. This paper shows that struggles for sustainability in Asia are mostly seen as quite distinct from the liberal democratic view. The dynamic relations of the privileged and underprivileged individuals and groups in the region are subject to continuous political antagonism associated with diverse cultural elements of power asymmetry in respective countries. In venturing sustainability as a concerted effort, plural civil society agendas in Asia involve cooperation and collaboration as well as the presence of fragmentation, disagreement and dialectical political forces. Transformative learning reshapes the individual and public spheres constitutively through interfaces of knowledge and transcendental values. The Asian realities also show that as long as politics continues to be situated mostly within the conventional practice of policymaking, negotiation and building coalitions with state authorities remains a central feature of civil society movements with varying outcomes. Civic engagement initiatives need to embrace political contestation and antagonism that construct policymaking, even as we recognize and appreciate the ongoing productive work of civil society actors within all three domains and at many levels of the social order.

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Climate change risk assessment and adaptation for loss and damage of urban transportation infrastructure in Southeast Asia

Lam Vu Thanh Noi [a*], **Richard T. Cooper** [b], **Dinh Thi Thuy Trang** [a], **Tran Quang Minh** [c], **Cao Thi Thu Huong** [d], **Spoann Vin** [e], **Sath Sitak** [f], **Rotchana Intharathirat** [g], **Jaranporn Lertsahakul** [h], **Tran Thi Tinh** [i]

[a] Southern Institute of Water Resources Research (SIWRR), Ho Chi Minh City, Viet Nam
[b] Southeast Asia START Regional Centre, Chulalongkorn University, Bangkok, Thailand
[c] Sub-Institute of HydroMeteorology and Climate Change (SIHYMECC), Ho Chi Minh City, Viet Nam
[d] Transport Development and Strategy Institute, Hanoi, Viet Nam
[e] Department of Economic Development, Faculty of Development Studies, Royal University of Phnom Penh, Cambodia
[f] Department of Green Economy, National Council for Sustainable Development, Ministry of Environment, Cambodia
[g] Regional Environment Office 9, Ministry of Natural Resources and Environment, Udon Thani, Thailand
[h] Green Style Co., Ltd, Bangkok, Thailand
[i] Dalat University, Lam Dong Province, Viet Nam
[*] *Corresponding author. Email: lamuem1980@gmail.com.*

ABSTRACT

Climate change (CC) will potentially have negative consequences for urban transportation infrastructure (UTI). It is important to improve our understanding of CC-associated loss and damage in relation to UTI. However, there is limited knowledge on how to practically assess loss and damage for UTI in the context of CC, and future-proof transportation planning. This study presents the results and experiences from the assessment of CC-related loss and damage to UTI in six cities of Cambodia, Thailand and Vietnam. It was found that the selected cities were highly vulnerable to CC given their location, exposure to sea level rise, storm surge, flooding, and salinity intrusion. Through analyses conducted using NK-GIAS software, economic losses for different flood scenarios were determined. The linkage between flooding and road damage was demonstrated, with maximum damage estimations under the most extreme flooding scenario of approximately 20 million USD for Hoi An, 3 million USD for Kampot and 21 million USD for Samut Sakhon, corresponding to water levels of 3.94 m, 4.7 m and 2.7 m respectively. Road damage was identified as a key impact related to CC. Further research is recommended to develop damage curves, addressing both flood depth and duration, to strengthen the NK-GIAS analyses.

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KEYWORDS

Climate change adaptation, flooding, loss and damage, urban transportation infrastructure, vulnerability assessment

HIGHLIGHTS

- This study highlighted the vulnerabilities of urban transportation infrastructure to climate change in six cities of Southeast Asia.
- Road networks were the main type of urban transportation infrastructure vulnerable to climate change in the selected cities.
- Analyses conducted with NK-GIAS revealed economic losses for each flood scenario examined.
- It is recommended that future research further develops road damage curves through laboratory analysis.

1. INTRODUCTION

Historical evidence and future climate change projections point to past and ongoing climate change in Southeast Asia. Increases in average annual temperature, changes in regional precipitation regimes, and sea-level rise (SLR) were evident during the last century. Future climate modelling projects temperature increases; precipitation to increase regionally though variable locally; and SLR to reach 30-40 cm by the end of this century (Hijioka et al., 2014; IPCC, 2013, 2014; NIC, 2009). Increased frequencies of weather extremes, tropical cyclones, floods and drought have been experienced in Southeast Asia (ADB, 2009, 2010). Projections indicate that climate change will lead to increased precipitation extremes related to monsoon and tropical cyclones, and flooding and coastal erosion caused by SLR will become a major threat to coastal communities (Hijioka et al., 2014; UN-Habitat, 2011).

Across Asia, communities will be increasingly vulnerable to the effects of climate change through its impact on water resources, agricultural production, natural resources, coastal and urban areas, and infrastructure (Hijioka et al., 2014). Given the region's high population, rapid urbanization and development, and economies reliant on agriculture and the use of natural resources, Southeast Asia is recognized as particularly vulnerable to the effects of climate change (ADB, 2009, 2010). Sea level rise will likely impact communities living in low-lying regions of Southeast Asia. In the Mekong River delta, it is estimated that a 1 m SLR could displace between 3.5 and 5 million people (IPCC, 2007). Groundwater abstraction and development policy may exacerbate the risk of flooding Hens et al. (2018). In low-lying regions of Southeast Asia, groundwater abstraction can contribute to subsidence, as evidenced in Bangkok and other cities of the region; and government policy may encourage development in flood-prone areas, such as in the city of Quy Nhon, Vietnam. Infrastructure is at increased risk from SLR and a variety of measures are required to address this issue, including adaption and mitigation approaches (Hens et al., 2018). Infrastructure, including transportation, is threatened by other climate change-related impacts, including flooding and landslides, storms and drought (World Bank, 2010).

Potential adaptation options to address climate change impacts include hard adaptation strategies, such as building new transportation systems, dikes, strengthening infrastructure; and soft options such as providing early warning systems, policymaking and planning (World Bank, 2010). Climate-proofing of urban transportation infrastructure might include hard adaptation options such as revising design standards for roads and associated assets such as culverts, bridges and embankments (ADB, 2010). Concerning adaptation, Southeast Asia is acknowledged as needing more investment in multiple sectors of the economy, with infrastructure, including transportation, highlighted as a priority area for support (ADB, 2009).

This project addresses the need to improve the mainstreaming of climate change into development planning of urban transportation infrastructure (UTI). An understanding of both the impacts of climate change and vulnerability of UTI is required. Vulnerability assessment can provide insights into potential loss and damage of infrastructure and support adaptation efforts through the sharing of knowledge on hazard factors, vulnerability profiles, and the building of community adaptive capacity. Such information can better inform decision-makers in implementing appropriate measures and policies for adaptation to climate change impacts, and especially for flood loss reduction. Vulnerability assessment techniques and tools attempt to incorporate knowledge across environmental, social and economic concerns; and the outputs of such analyses can provide a stronger evidence base for determining vulnerabilities and sensitivities of systems, whether at regional or city level, related to various climate change scenarios (Füssel & Klein, 2006).

The adoption of appropriate adaptation measures and strategies for UTI will be informed from the variety of approaches already implemented in cities and economic sectors, including transportation. Recognized challenges include inappropriate planning due to a lack of climate change awareness and information, with solutions typically informed by assessing investment costs and benefits. This study is expected to support cities and countries by contributing knowledge and capacity building to facilitate improved climate change adaptation for UTI planning.

2. OBJECTIVES

This study aims to advance knowledge on loss and damage of UTI in the context of climate change in selected cities in Southeast Asia and bring effective and applicable climate change risk assessment tools and methods to UTI planning and management. To achieve this outcome, the objectives of this study are two-fold:

1. Develop a methodology for assessing loss and damage for UTI in the context of climate change at the city level; and

2. Identify climate change adaptation measures for incorporation into urban transport planning

The study examines the linkages between hazards, vulnerability and adaptive capacity, focusing on flood-related loss and damage for roads, which form the main UTI in the study areas. It also helps identify adaptation measures for incorporation into urban transport planning at the city level. Limitations of the study relate to the scope of the loss and damage assessment for UTI, which only considers the negative impacts of climate change in the context of urbanization. Furthermore, hydraulic effects were addressed through integrating road damage curve findings from the literature review, as appropriate laboratory experiments were out of the study's scope.

3. METHODOLOGY

Six cities (two cities per country) were selected for conducting rapid assessments. These assessments focused on loss and damage of UTI in the context of climate change by applying Participatory Rural Appraisal (PRA), Impact Matrix, and Multiple Criteria Analysis (MCA). Based on the rapid assessment findings and city selection criteria, three pilot cities were selected (one city per each country) for subsequent vulnerability assessments (VA) at the community level using NK-GIAS. The NK-GIAS is specialized geographic information system (GIS) software that enables the management, display, editing and analysis of spatiotemporal data. It is used here for estimating the loss and damage for each type of UTI associated with key hazards.

The loss and damage estimation process utilizing NK-GIAS (Samarakon, Nakamura, & Hunukumbura, 2012) is outlined as follows in four steps and also shown in Figure 1. The project considers climate change-related disaster risk as a function of

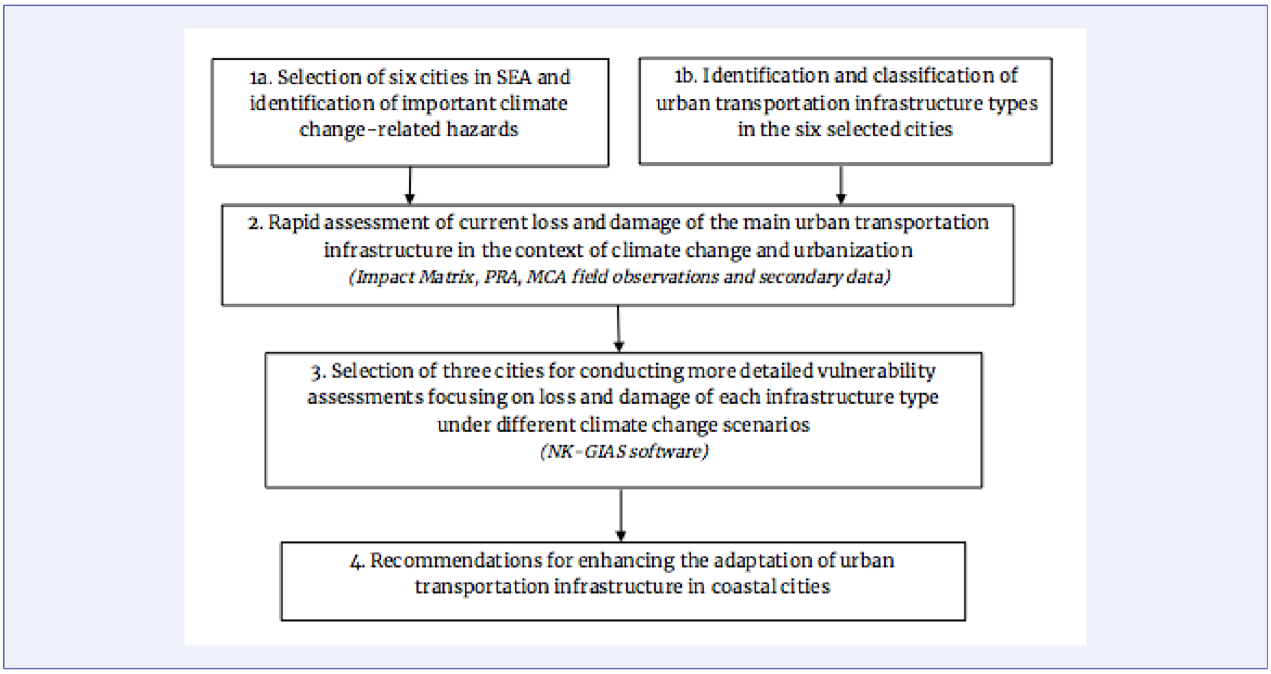

FIGURE 1. Overall methodological framework.

the interaction between hazards, vulnerability, and adaptive capacity.

In step 1a, six cities in three countries (two per country) were selected as the study areas. City selection was based on a literature review concerning climate change-related risk, as well as from secondary data concerning climate change impacts and loss and damage of UTI.

In step 1b, each country project partner reviewed and classified UTI types in each city based on a literature review, survey, and consultation with key stakeholders (MPWT, 2009, 2013; Vinh Long PC, 2015; Hua Hin Municipality, 2015; Green Style Co., Ltd., 2018; Samut Sakhon Municipality, 2018; Hoi An Transportation Department, 2017).

In step 2, rapid assessment (Noi & Nitivattananon, 2015; Füssel & Klein, 2006) was conducted to determine the current loss and damage of urban transportation infrastructure associated with identified hazards based on current and historical data at the city level over a period of 5 to 10 years. The assessments addressed the costs of recovery/repair and percentage of UTI damaged after a flood, storm, heavy rain, and landslide; applied PRA to identify hazards, associated vulnerability, and current adaptive capacity; and used Impact Matrix and MCA to estimate UTI vulnerability to hazards.

In step 3, findings from Step 2 were used and more detailed vulnerability assessments were conducted for one pilot city per country to estimate loss and damage for the main UTI types. Loss and damage were estimated using NK-GIAS software (Samarakon et al., 2012) for the most vulnerable UTI. The loss and damage estimation process utilizing NK-GIAS is outlined as follows: (1) selection and processing of baseline data including topography, meteorology, hydrology; (2) creation of infrastructure map density layers; (3) analysis of hazard impacts under different climate change scenarios (flooding scenarios); (4) generation of hazard maps showing projected future maximum flood depths; (5) development/adaptation of damage curves for each type of UTI (i.e., roads) from surveys, secondary data, and literature review; (6) estimation of damage for each type of UTI by applying the function of total structural damage for the UTI types based on the results of step (3) and (4); and (7) summarizing of damage estimations (cost estimations) and the proposing of recommendations.

In step 4, the research methodology and findings were shared with stakeholders through workshops, and recommendations for enhancing the adaptation of urban transportation infrastructure management in coastal cities were discussed. During the implementation of the project, the team had the opportunity to discuss the research and ongoing findings with various government departments, and at the conclusion and approval of the final report, the findings will be shared with key stakeholders. Although not part of the project, it would be interesting as a future initiative to follow up with stakeholders to discuss progress in mainstreaming climate change into planning for urban transportation infrastructure.

4. RESULTS AND DISCUSSION

4.1. Rapid vulnerability assessment of UTI in selected cities

Selection of the three countries in Southeast Asia for the study was based on consideration of their vulnerability to climate change, especially to SLR and the existing research network for conducting a collaborative project between the selected countries. The city selection criteria used in the assessment were representation, significance, and data accessibility. Based on the literature review, the cities selected for the study were Hoi An and Vinh Long in Viet Nam, Hua Hin and Samut Sakhon in Thailand, and Kampot and Sihanoukville in Cambodia (see Figure 2 and Table 1).

Given that approximately 70% of Hoi An is situated below an elevation of 3 m, it is highly vulnerable to SLR (Hoi An PC, 2015; SIHYMECC, 2015). The need for implementing climate change adaptation measures to reduce threats to natural resources, the local community, economy and transportation assets is recognized. Presently, the city prioritizes adaptation measures to reduce coastal erosion.

Vinh Long city is highly vulnerable to climate risks, especially to rising sea level and increased rainfall, and their combination with high tide has the potential to exacerbate flooding (Vinh Long PC, 2015). Given its low topography, the city is exposed to flooding with increasing duration and magnitude, with UTI already affected by flooding. In the city, hard and soft adaptation measures have been developed, but those for UTI are insufficient.

In Thailand, Hua Hin is coastally situated, with inland flooding due to runoff, a key climate-related hazard, which may worsen in the future with increased rainfall extremes during the southwest monsoon season. In addition, typhoons and tropical storms are described as being of ‘relatively high risk’ in southern parts of Thailand, including Hua Hin city (Thailand Meteorological Department, 2012). In the city, climate-related hazards have the potential to impact overall development, including UTI functions, and to increase the costs of repair and maintenance for UTI. Climate change adaptations are being implemented in the city but are not targeted at UTI.

Located along the northern edge of the Gulf of Thailand, Samut Sakhon is at risk from SLR and storm surge, as well as from coastal erosion and saltwater intrusion. The city has a large population with a high density of infrastructure, including UTI that is vulnerable to climate change impacts. Climate change adaptation measures are being implemented, which focus mainly on hard infrastructure solutions (Samut Sakhon Municipality, 2019).

Kampot city in Cambodia is vulnerable to storms, rainfall extremes, floods and saltwater intrusion (MPWT, 2013; JICA, 2015). These hazards directly affect important facilities that provide services for water supply, sanitation, and road infrastructure, all of which are in an underdeveloped state. The effects of climate change on urban infrastructure have previously been studied: roads, dikes, canals, bridges and railways, drainage systems and water supplies are all vulnerable to storm, floods, and sea level rise (RUPP, 2018; JICA, 2015).

City	General information	Urban transportation infrastructure
Hoi An	- Total area: 6,148 km^2 (Hoi An PC, 2019). - Population: 98,599 (Hoi An PC, 2019). - Located in a vulnerable coastal region and downstream of the Vu Gia–Thu Bon River. - Recognized as a World Heritage Site since 1999. - The city's location and region are especially susceptible to climate-related impacts. Much of Hoi An is low-lying, with 70% of the city below an elevation of 3 m (SIHYMECC, 2015).	- The width of the main inland road system is 5–7 m and in some places up to 14–20 m excluding pedestrian walkways (Hoi An PC, 2015). - The inner-city road network is old and small, and related infrastructure old. The total road length is 133.6 km, of which 67% is bituminous (Department, 2017).
Vinh Long	- Total area: 47.82 km^2 (Vinh Long PC, 2019). - Population: 98,599 (Vinh Long PC, 2019). - Located in the central area of the Mekong Delta, between the Tien River and Hau River. - Vulnerable to the combination of rising sea level, and heavy rainfall, which can result in flash flooding, and high tide (Vinh Long PC, 2015).	- Located in an area with a dense stream network, the city has access to water and inland road networks. - Some urban roads are susceptible to flash flooding of up to 20-30 cm depth, causing traffic congestion and damage. These roads do not comply with the required rain drainage standard (Vinh Long PC, 2015). - The city is exposed to flooding of increasing duration and magnitude given the city's lowland setting, with UTI already affected by flood (Vinh Long PC, 2015). - Hard and soft climate change adaptation measures are being implemented, but those for UTI are not adequate (Vinh Long PC, 2015).

Continued on next page

Table 1 continued

City	General information	Urban transportation infrastructure
Hua Hin city	- Total area: 86.36 km^2. - Population: 65,983 (Municipality, 2019) - Hua Hin is a popular coastal resort and the largest coastal settlement in the Thai province of Prachuab Khiri Khan. - Hua Hin has a rapidly growing population and large tourist population (Municipality, 2014). - Inland flooding caused by runoff will likely become greater in the future with increasing rainfall extremes. During the rainy season, flash flooding is an issue in a lower-lying part of the city (Hua Hin Municipality, 2015; JICA, 2013).	- The main UTI are road and rail networks and related infrastructure. - Climate change adaptation efforts are being implemented but are not targeted at UTI (Hua Hin Municipality, 2015; JICA, 2013) - Transportation planning does not extend beyond a'densification' road development target of 1 km per km^2(currently 0.8 km/ km^2) as per the report of Hua Hin Municipality (2015)
Samut Sakhon city	- Total area: 1,033 km^2. - Population: 68,381 (Samut Sakhon Municipality, 2019) - Samut Sakhon province is part of the Bangkok Metropolitan Region and comprises three districts, of which the capital district, Meuang Samut Sakhon, and its coastal municipal sub-districts are of interest in this study. - Climate-related hazards include coastal flooding from SLR, storm surge, and coastal erosion (Samut Sakhon Municipality, 2018).	- Key UTI comprise road and rail networks and related assets, which are at risk from climate-related hazards. - Adaptation measures are being implemented, which focus mainly on hard infrastructure solutions (Samut Sakhon Municipality, 2018; Green Style Co., Ltd., 2018). - Engineering adaptation measures include ground elevation and sea wall construction, though leakage through the latter was reported (Samut Sakhon Municipality, 2018).

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Table 1 continued

City	General information	Urban transportation infrastructure
Sihanoukville city	- Total area: 85.56 km^2 - Population: 79,745 (Administration, 2019). - Sihanoukville city is described as an economic zone port and tourism development city. - The vulnerability of Sihanoukville was previously assessed (UN-Habitat, 2011) and SLR was identified as a key risk factor, rising up to 1.5 m by the end of the century, with resultant flooding a threat to low elevation areas and with impacts potentially exacerbated by storm surge and high tide (MPWT, 2013; JICA, 2015).	- Sihanoukville has 48,385 km of existing roads in four districts, of which 3,668 km are constructed with concrete, 25 km with laterite, 4.8 km with constructed earth, and 4.74 km with unconstructed earth. - The railway from Phnom Penh to Sihanoukville is 266 km in length (MPWT, 2013). - The Department of Public Works and Transport spend more than 50,000 USD annually for repairing and maintaining the road system (MPWT, 2013).
Kampot	- Total area: 39.41 km^2 - Population: 35,874 (Kampot Administration, 2015). - This city is vulnerable to various climate hazards, including extreme winds, SLR, prolonged drought, saltwater intrusion, and floods caused by intensive rainfall. Historical evidence reveals the damage of such extremes to residents and city infrastructure (MPWT, 2013; JICA, 2015). - Several communes are highly vulnerable to SLR, particularly Chum Kriel, Traeuy Koh, Boeung Sala Tboung and Russei Srok Keut. Flooding of salt farms and saltwater intrusion represent key impacts of SLR (MPWT, 2013).	- The road system in Kampot has a total length of 45,117 km which extends over five districts, of which 1,556 km of road are constructed of concrete, 33.224 km with laterite, 2.848 km with earth and 4.760 km with unconstructed earth (MPWT, 2013). - A variety of infrastructure assets, including roads, dikes, canals, bridges and railways, drainage systems and water supply systems, are vulnerable to storm, floods, and SLR. Substantive economic, social and infrastructural damage results from these hazards (RUPP, 2018).

TABLE 1. Key information of three cities chosen for rapid vulnerability assessment.

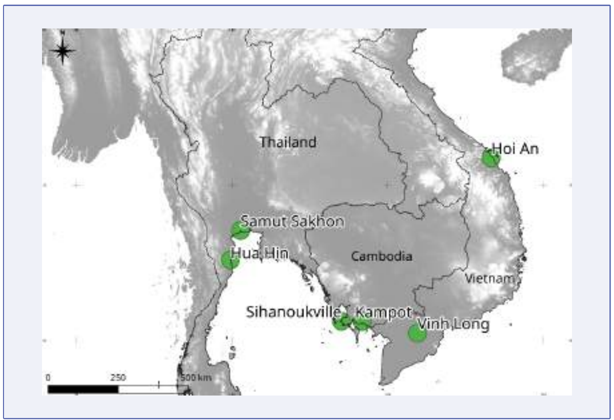

FIGURE 2. Locations of six cities where the research was conducted .

The Cambodian city of Sihanoukville is vulnerable to SLR, storms and flooding. These hazards cause coastal erosion and flash flooding in the city and resultant infrastructure losses include UTI damage (JICA, 2015; MPWT, 2013). Current coastal infrastructure will not adequately cope with increased flood risk and extreme events due to climate change. Furthermore, key UTI is inadequate and of poor quality (e.g., earthen roads), so it is difficult to reduce the impact of flood events, and the lack of relevant expertise and access to funds offer considerable challenges. Overall, the vulnerability of the city has been ranked as 'medium', but some areas along the coastline are recognized as being highly vulnerable.

A variety of factors were assessed for each city-specific rapid vulnerability analysis (RVA) (Noi & Nitivattananon, 2015). Inputs were sought through interviews with local experts; exposure to climate change-related hazards; UTI vulnerabilities; and each city's particular geographic settings and social and economic characteristics. Current and potential approaches to adaptation and adaptive capacity were discussed, and the vulnerability of each city ranked accordingly. A city was given the highest vulnerability ranking if adaptation measures were absent and described as having 'low vulnerability' if some adaptation measures were currently being implemented. If a city had high adaptive capacity, it was defined as having 'low vulnerability' and with 'negligible vulnerability' if there were no climate-related hazards.

A summary of the RVA results is given in Figure 3.

Based on rapid assessment with group discussions and expert interviews, Table 2 presents the sensitivities of the six selected cities and their capacity to adapt to current and projected climate-related hazards. Table 2 shows that when the adaptive capacity of a city is low, the city may be vulnerable or highly vulnerable to hazards, or if exhibiting medium or a higher level of adaptive capacity, the city may have low vulnerability to hazards. If adaptive measures are lacking, vulnerability is higher. All hazards were considered with regard to their impacts on the main UTI, including roads, ports/harbours and rail. Based on evidence derived from field observations and expert interviews, the effectiveness of implementing a climate change adaptation measure was shown for the Samut Sakhon River dike construction in 2009. Dike construction was found to reduce flood frequency and depth; and total loss and damage, estimated from socioeconomic and natural resources, was reduced by over 70% (Samut Sakhon Municipality, 2019).

Table 2 shows that the main climate change-related factors affecting UTI are flood and SLR, which represent potential hazards for roads in all of the selected cities. In addition, the main UTI that is vulnerable to climate change in the selected cities are roads, ports/harbours and rail (roads are more vulnerable to flood). Based on RVA results, three cities (one in each country) that were identified with the highest UTI vulnerability (i.e., Hoi An, Kampot and Samut Sakhon) were selected for a more detailed vulnerability assessment, which focused on loss and damage of roads under different flood scenarios.

4.2. Assessment of UTI damage by applying NK-GIAS

4.2.1. Damage curve development for road damage

According to de Bruijn (2005) , the damage function for infrastructure is defined as follows:

$$ED_{infrastructure} = \alpha(d).D_{max}.\varepsilon \tag{1}$$

Country/ City	Vulnerability	Hazards							
		Storm	Flood	SLR	Saline intrusion	Drought	Coastal Erosion	Land Subsidence	Land slide
Hoi An, Vietnam	Level	+++	+++	+++	-	+	+++	+	+
	Most Vulnerable	Roads	Roads	Roads		Ports/ harbours	Roads	Roads	_
Vinh Long, Vietnam	Level	+	+++	++	+	+	+++	+	++
	Most Vulnerable	Roads	Roads	Roads	Ports/ harbours	Roads	roads	Roads	Roads
Kampot, Cambodia	Level	++	+++	++	-	+	++	_	+
	Most Vulnerable	Roads	Roads	Roads	-	Rail	Ports/ harbours	_	Roads and rail
Sihanoukville, Cambodia	Level	++	++	++	+	+	++	-	+
	Most Vulnerable	Roads	Roads	Roads	Ports/ harbours	Rail	Roads	Roads	
Hua Hin, Thailand	Level	+	+	++	+	+	++	+	+
	Most Vulnerable	Roads	Roads	Roads	Ports/ harbours	Rail	Rail and Roads	Roads	Roads
Samut Sakhon Meuang, Thailand	Level	+	+++	+++	-	+	+++	+	-
	Most Vulnerable	Roads	Roads	Roads		Ports/ harbours	Roads	Roads	

FIGURE 3. Summary of the RVA results for selected cities. Source: experts' opinions and survey outputs (2015). Legend: + (green) = Negligible; ++ (yellow) = Low; +++ (red) = High.

where ED represents economic damage in US dollars (USD), α is the damage factor of the damage category, d is water depth (m), D_{max} is the maximum damage per unit in category (USD/m^2), and ε is the conversion factor or extra factor.

This study adapted the damage function to calculate road damage as follows:

$$RoadD = \sum(\alpha_i.D_{imax}.S.\varepsilon) \quad (2)$$

where

- D_i max is the maximum damage per unit of road (construction cost as USD/m^2)
- S is cell size (m^2)
- α_i is the roads damage factor depending on flood depth (h)
- ε= 1: The road was digitized from road and digital elevation maps, which included detailed roadways. The roadways can be accurately measured, so there is no correction factor and ε = 1.

The relationship between flood depth and percentage of road damage, as given by Chen (2007) and De Bruijn (2005), was adopted, where the road damage factor and flood depth are correlated and defined in the road damage curve as follows:

$$\begin{aligned} &If\ x(h) < 0.91m,\ y(\alpha)\ = \\ &\quad 5.581x^4 - 7.9492x^3\ +\ 4.4176x^2 \\ &\quad -\ 0.5439x\ +\ 0.0018 \\ &If\ x(h) \geq 0.91m,\ y(\alpha) = 1 \end{aligned} \quad (3)$$

The α values were calculated based on flood depth, with the results presented in Table 2.

The α value was applied for calculating road damage based on flood depth in the calculation of cost damage.

4.2.2. Results of maximum road damage under different flood scenarios

The following section summarizes road damage results from the main flood scenarios examined. The detailed steps for calculating road damage using

x (Flood depth in meters)	Y (α)
0	0.00
0.15	0.00
0.35	0.10
0.60	0.27
0.75	0.49
0.91	1.00

TABLE 2. Road damage factors (α). Sources: adapted from Jorik Chen (2007) and De Bruijn (2005).

NK-GIAS followed the methodology described in section 2. The NK-GIAS software was validated and calibrated using historical flood depth data and the actual damage to roads in the case study areas. Actual road damage was compared with the calculated results of maximum road damage, and the model then adjusted for final validation and calibration before being applied to the three selected cities.

4.2.2.1. Flood scenarios. Flood scenarios were based on maximum water levels as recorded from events in the last 10 to 20 years or the highest historical water level based on data available. The data used for flood scenario analysis had the following H_{max} values (m) where Water level (H_{max}) = flooding depth (h) + ground elevation (with all units in meters): H_{max} = 3.40 m in Hoi An on November 1964 (SIHYMECC, 2015); H_{max} = 4.0 m in Kampot on September 2013 (JICA, 2015); and H_{max} = 2.7 m in Samut Sakhon on October 2011 (Green Style Co., Ltd., 2018; Samut Sakhon Municipality, 2019). In addition, for estimating maximum road damage, new flood scenarios were created by increasing the water level (H_{max}) as follows:

Scenario 1: The mean water level over the last 20 years in the study areas.

Scenario 2: The water level that is equal to the maximum flood depth experienced over the last 20 years in the study areas.

Scenario 3: The water level that is equal to an increase in flood depth of 3 to 7% compared to the maximum flood depth over the last 20 years in the study areas (based on topographic characteristics of each city and expert consultation).

Scenario 4: The water level that is equal to an increase of 10 to 17.5% compared to the maximum flood depth over the last 20 years in the study areas (based on topographic characteristics of each city and expert consultation).

4.2.2.2. Calculation of maximum road damage. It is assumed that damage occurs after inundation and the cost of recovery to the state/condition of the road before flooding is considered as road damage.

Hoi An City

The main urban roads investigated in the study are detailed in Table 3.

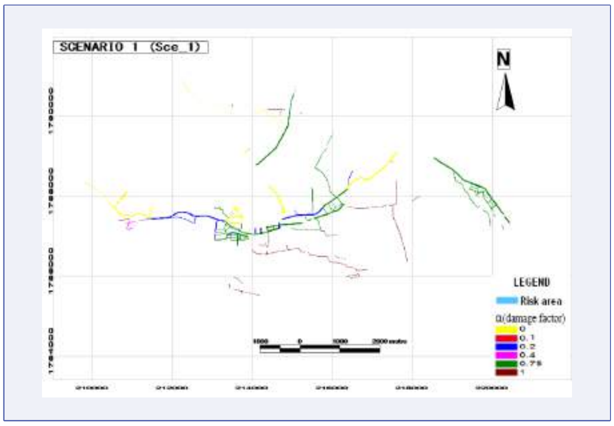

FIGURE 4. Flood risk map for urban roads under SCE_1 in Hoi An city.

The road damage factors determined in Hoi An under scenario 1 (SCE_1) are presented in Figure 4, and road damage costs for each scenario and type of urban road are shown in Table 4.

Based on secondary data and expert consultation in Hoi An (2017), the estimated road damage due to flooding in the city mostly relates to the road surface. In addition, as discussed during the transport expert consultation, the road foundation can minimize damage from flood due to robust road construction and other adaptation measures such as dikes and embankments (Hoi An Transportation Department, 2017). Furthermore, this research only considers hydraulic effects based on the road damage curve and does not apply any hydraulic modelling. According to the results, the maximum road damage is 20.3 million USD under flooding scenario 4 (Table 4).

Kampot city

The various metrics of urban roads within Kampot city are presented in Table 5.

Road damage factors are shown in Figure 6 for scenario 1, and damage costs for each kind of road with regard to each flood scenario in Kampot are presented in Figure 7 and Table 6.

Findings reveal that the total cost of loss and damage from urban flooding under each scenario is substantial (Table 6). Under scenario 1, with an

Roads	R1 (AC, SDP, CC)	R2 (Pen, AC, CC, Earth)	R3 (AC, Pen, CC)	R4(AC, Pen, CC)	R5 (AC, CC, Pen)	Total
Length (m)	84,024	20,742	7,078	6,146	15,620	133,610
Percentage (%)	62.89	15.52	5.30	4.60	11.69	100.00
Surface (m^2)	1,247,859	239,209	62,936	45,201	71,195	1,666,401
Percentage (%)	74.88	14.35	3.78	2.71	4.27	100.00
Cost (USD/m^2)	90	90	82	68	38.83	

TABLE 3. Road types in Hoi An city. Source: Hoi An Transportation Department (2017) and VMC (2015). Note: AC: Asphalt concrete; Pen: Penetration; CC: Cement concrete; SDP: Surface dressing pavement.

		Name of scenario			
		SCE_1 (m)	**SCE_2 (m)**	**SCE_3 (m)**	**SCE_4 (m)**
		2.72	**3.4**	**3.61**	**3.94**
Road damage	R1	621,335	6,173,497	8,886,456	11,344,227
	R2	74,411	776,228	1,165,390	1,528,950
	R3	71,559	852,295	1,187,013	1,380,114
	R4	550,092	3,992,492	4,562,281	4,631,773
	R5	104,912	884,930	1,220,152	1,386,971
	Total (USD)	1,422,311	12,679,444	17,021,294	20,272,036

TABLE 4. Total road damage under different scenarios in Hoi An City.

	Road type in Kampot city				
	R1 (AC)	**R2 (CC)**	**R3 (DBST)**	**R4 (DBST)**	**Total**
Length (m)	9,295	3,542	14,150	21,945	48,932
Surface (m^2)	103,182	37,246	142,017	149,952	432,397
Length (%)	19%	7%	29%	45%	
Surface (%)	24%	9%	33%	35%	
Cost (USD/m^2)	48	44.18	34.4		

TABLE 5. Road types in Kampot city. Note: DBST = Double Bituminous Surface Treatment.

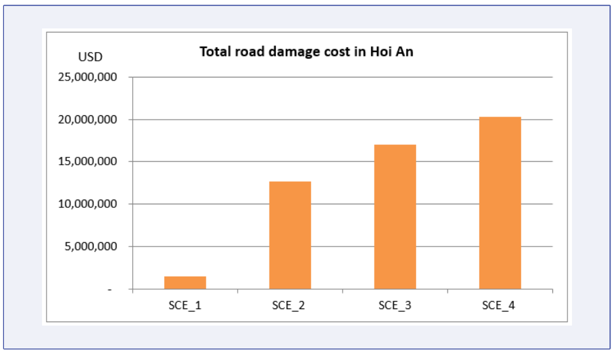

FIGURE 5. Total road damage in Hoi An under different flooding scenarios.

average flood depth of 0.3 m, costs amounted to more than 952K USD, which is the lowest economic loss in comparison to the other three scenarios. The road damage cost for scenario 2 (SCE_2), which reflects the maximum flood within the last two decades, is higher than the base scenario with costs amounting to 2.7 million USD and is comparable to

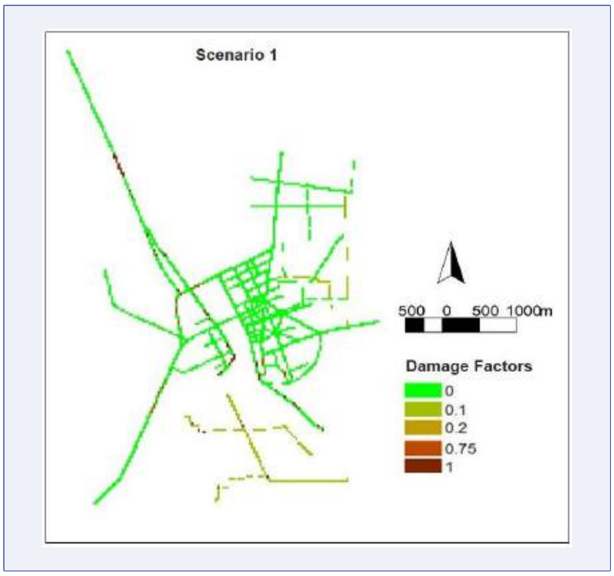

FIGURE 6. Flood risk map for urban roads under SCE_1 in Kampot city.

the cost of scenario 3. However, when the water level increases by 17.5% compared to scenario 3 (SCE_3), the economic loss peaks at about 3 million USD.

Results also indicate how different road surfaces impact costs. Asphalt concrete is most vulnerable to economic loss when flooding occurs in urban areas compared to other road types. Cement concrete roads are the choice for commune development due to limited resources and geographical availability. Laterite roads were mostly used in peri-urban communities and for connecting main roads in the city. The economic loss of laterite roads is lower compared to other types, although representing 45% of the total road length in the city. The DBST road type is most common in the city and is the second most vulnerable road surface type to economic loss by flood impact, with cement concrete roads being more vulnerable.

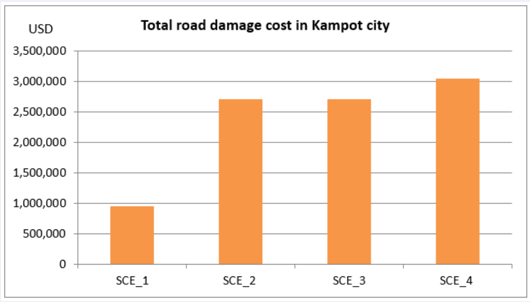

FIGURE 7. Total road damage cost by flooding scenario in Kampot city.

The cost of road damage under different scenarios is shown in Figure 7. Results indicate that the base scenario is less vulnerable under the current situation of road infrastructure development. Alternative scenarios show substantive impacts on UTI, especially for AC and DBST road types. Estimated damage costs were not significantly different between scenarios 2, 3 and 4 in the model due to the limitation of the DEM used in Kampot city (30 m resolution). A higher DEM resolution would have likely improved findings but was not available.

Samut Sakhon

The various metrics of road infrastructure in Samut Sakhon are presented in Table 7.

Samut Sakhon has only three types of urban road, including reinforced concrete (RC) and asphalt (A) and highway with RC surfaces. The total length of highway road is 39,215 km which represents around 9% of the road surface in the city.

FIGURE 8. Flood risk map for urban roads under SCE_1 in Samut Sakhon city.

Road damage factors are shown in Figure 8 for scenario 1, and the estimation of road damage under different flooding scenarios is shown in Table 8 and Figure 9.

Samut Sakhon is a low-lying city with mean elevation under 1.8 m (Samut Sakhon Municipality, 2018). According to Table 8 and Figure 9, using road damage calculations based on scenario 3, the water level was 2.79 m which was about 3.3% higher than the historical H_{max} in October 2011 (Green Style Co., Ltd., 2018). Ongoing construction of a river dike will protect much of the city (as of 2019, 500 m remains to be built), which is a critical climate change adaptation measure in the study area. However, with only 0.09 m of increased flood depth under scenario 3, the economic loss increases from 14.5 to 16.7 million USD (a 15% increase). Under scenario 4, with a flood depth increasing by 0.29 m compared to scenario 2, losses increased by 44.7% from 14.54 to 21.04 million USD.

Results indicate that under scenario 1, the current situation of road infrastructure development is vulnerable. Discussions with the Disaster Pre-

		Name of scenario			
		SCE_1 (m)	**SCE_2 (m)**	**SCE_3 (m)**	**SCE_4 (m)**
		3.3	**4.0**	**4.3**	**4.7**
Road damage	R1	516,987	1,623,104	1,623,104	1,647,624
	R2	27,387	223,745	223,745	508,044
	R3	393,855	758,393	758,393	779,599
	R4	13,860	104,445	104,879	105,940
	Total (USD)	952,089	2,709,688	2,710,122	3,041,208

TABLE 6. Total road damage under different scenarios in Kampot city.

	Road type in Samut Sakhon city			
	R1 (RC)	**R2 (A)**	**R3 (Highway)**	**Total (m)**
Length (m)	18,233	23,029	39,215	80,477
Surface (m2)	332.20	272.80	63.00	668
Length (%)	23%	29%	49%	
Surface (%)	50%	41%	9%	
Cost (USD)	725	29	300	

TABLE 7. Road type in Samut Sakhon city. Source: Samut Sakhon Municipality (2018). Note: RC = Double Bituminous Surface Treatment.

		Name of scenario			
		SCE_1 (m)	**SCE_2 (m)**	**SCE_3 (m)**	**SCE_4 (m)**
		2.4	**2.7**	**2.79**	**2.99**
Road damage	R1	1,921,350	3,912,921	4,409,701	5,272,966
	R2	3,534,049	6,934,664	7,776,366	9,069,439
	R3	1,139,290	3,698,020	4,528,451	6,703,217
	Total (USD)	6,594,689	14,545,605	16,714,518	21,045,622

TABLE 8. Total road damage under different scenarios in Samut Sakhon city.

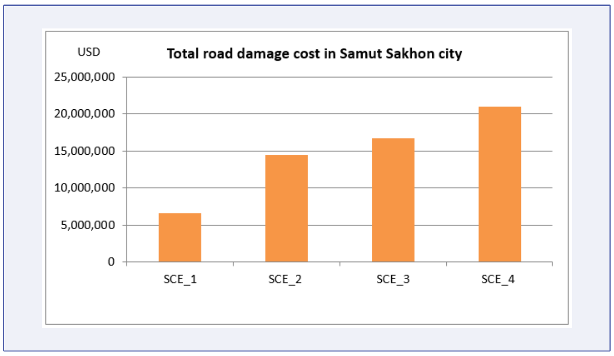

FIGURE 9. Total road damage costs under each flooding scenario in Samut Sakhon city.

vention Department indicated that two subdistricts, Tha Shalom and Mahachai, were flooded by a mean flood level of 0.6 m (water level is 2.4 m) before dike construction. Dikes were built between 2007 and 2009, and flood depth is now always under 0.6 m and only in Chalom subdistrict which is an area outside of the dike (Samut Sakhon Municipality, 2019).

Alternative scenarios show greater impacts on UTI, especially for the RC road type. Estimated damage costs were significantly different between scenarios 2, 3 and 4 due to differences in inundation areas. One factor supporting more accurate determination of the inundated areas (and flood depths) would be to use a DEM with higher resolution (2 m resolution) in Samut Sakhon city.

5. CONCLUSIONS AND RECOMMENDATIONS

This study defined an assessment methodology for applying climate change risk assessment for UTI at the local level. An enhanced understanding of potential hazards, vulnerabilities and adaptive capacity was achieved through adopting RVA approaches and using NK-GIAS for more detailed analyses. Based on the review process adopted, the six cities selected in this study were shown to be vulnerable with regard to a number of aspects. Given their geographic settings, the six cities were especially at risk from flooding and salinity intrusion, with risk further exacerbated by SLR and storm surge. Road infrastructure was identified as being most at risk from the impacts of climate change, and current policies for UTI lack considerations of climate change. In all of the six cities, flooding and SLR represent potential hazards as identified through the RVA.

This study demonstrates how economic losses can relate to different flood scenarios, where increasing depth directly increases damage costs in each city. Based on the results from the NK-GIAS analysis under scenario 1, the estimated maximum damage costs for Hoi An, Kampot, and Samut Sakhon were 0.95, 1.5 and 6.5 million USD, respectively. The flood scenarios examined provide a range of possible damage costs by city: under SCE_4 (the most extreme scenario examined), estimated maximum damage costs reach 20 million USD for Hoi Anh, 3 million USD for Kampot, and 21 million USD for Samut Sakhon. Note, however, that the actual damage costs reduced considerably following dike construction in Samut Sakhon in 2009, with the dike reducing flooding under SCE_1 to SCE_3 (the water level is lower than the dike height), but the maximum damage cost may reach 21 million USD under SCE_4.

Two key constraints to the assessment methodology were identified: reduced accuracy in the flooded area may result from using a DEM with low resolution, which preferably should not be larger than 5 m for the input DEM; and conducting flood damage assessment should apply a suite of approaches for investigating all vulnerability factors and the sensitivities of each city to flooding.

Engineered adaptation measures that have been implemented by local governments to address flooding include the development of dikes and embankments for long-term protection and the use of sandbags as a temporary measure. The effectiveness of dike protection is demonstrated in Samut Sakhon, where after completing its construction around the city, the frequency of flooding was reduced by more than 70% (Samut Sakhon Municipality, 2019). However, concerns about incorporating climate change into policy and planning is a more recent consideration. Existing climate change action plans (to 2050) for Vinh Long and Hoi An (Viet Nam) are rather general and lack details with regard to UTI and, more specifically, associated design and construction requirements.

A number of recommendations are proposed based on the study's findings: (i) to encourage the mainstreaming of climate change into policy and planning, training should be provided to relevant government authorities and especially for local government staff in Hoi An, Kampot and Samut Sakhon cities; (ii) to encourage collaboration among the private sector, city municipalities and local government to ensure UTI development is both cost-efficient and climate-resilient; and (iii) to utilize best available evidence on flood frequencies and historical water levels to inform infrastructure design (e.g., for strengthening the foundation of coastal and riverside road bridges and culverts); (iv) the results of the UTI damage assessment might be improved if research could have focused on developing new damage curves in the laboratory using physical models to simulate damage related to both flood depth and duration. Further research is recommended to conduct laboratory experiments to refine road damage curves for strengthening the NK-GIAS analysis.

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Case study

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Integrated analysis of climate, land use and water for resilience urban megacities: A case study of Thailand and Viet Nam

Sathaporn Monprapussorn [a] *, **Le Phoung Ha** [b]

[a] Srinakharinwirot University, Bangkok, Thailand
[b] Viet Nam Institute of Meteorology, Hydrology and Climate Change, Hanoi, Viet Nam
* *Corresponding author. Email: sathaporn@g.swu.ac.th.*

ABSTRACT

This research aims to explore the integration of land use, climate, and water resources for urban resilience in Bangkok, Thailand and Hanoi, Viet Nam, both of which are megacities of Southeast Asia. Climate projections using the WorldClim database for 2050 in Bangkok reveal an increase in temperature by 8.2 percent, while precipitation will tend to slightly decrease by 7.47 percent compared to 1960-1990. The model also forecasts warmer temperature by 10.97 percent and a slight decrease by 2.6 percent in precipitation in Hanoi by 2050. Scenario-based land use projection using the CLUMondo model reveals a higher urban expansion rate in Bangkok and Hanoi under "business as usual" (BAU) scenarios. Regarding the Green Growth (GG) scenario, forest cover in Hanoi is expected to increase at a higher rate than Bangkok by 2050. A projected increase in water demand by 2050 in both cities will come from agriculture and industrial expansion, an increase in the population, and higher living standards. Bangkok and Hanoi are particularly vulnerable to water shortage from less precipitation in 2050, which will cause water supply problems in the future. The combined impact of climate and land-use change by 2050 may lead to urban water supply problems. Urban planners and policymakers should consider the significant impacts of water security and prepare for city mitigation and adaptation to cope with these changes.

KEYWORDS

Climate change, land use, water resources, Bangkok, Hanoi

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HIGHLIGHTS

- Projection of climate change by 2050 in two urban megacities in Southeast Asia.
- Scenario-based method for land-use prediction by 2050 based on driving forces.
- Water demand analysis considering socio-economic change.

1. INTRODUCTION

Water is a crucial resource for human survival in Southeast Asia. More than five billion people could suffer water shortages by 2050 due to climate change, leading to increased demand as well as polluted water supply. The rapid urbanization in megacities has challenged authorities to respond to the demand for clean and adequate water. Climate change can have a large impact on water resources through rising sea levels and intensifying changing hydrological cycles. More frequent and heavier droughts, rainfall and heatwaves are forecasted or already observable as clear evidence of climate change in Europe (Costa et al., 2015; Guerreiro, Dawson, Kilsby, Lewis, & Ford, 2018). In the Mediterranean river basin, drinking water provisioning is expected to decrease between 3% and 49% and hydro-production power will decrease between 5% and 43% due to the impact of climate change (Bangash et al., 2013).

Human interventions on the water cycle can degrade both water quantity and quality in several ways, i.e., damning rivers for electricity; withdrawing water for farming. The most obvious example is the conversion of forest land into agriculture and urban areas, which causes an alteration in the urban water balance. Lei, Zhang, Chen, and Zhang (2016) explored the water scarcity problem in northern Chinese cities and suggested that effective rural land-use management can mitigate drought risks and ensure food security. In terms of socio-economic, urban population growth is expected to occur at a very rapid scale and be linked to low quality of life and poverty issues, increasing the size of vulnerable populations in cities and placing additional pressure on decreasing water supplies resources (Pageler, 2009).

1.1. Bangkok

As the capital city of Thailand, Bangkok occupies 1,568.7 square kilometres and is located in the Chao Phraya River central delta plain. The rapid growth of Bangkok in the past lacked systematic urban planning and regulation. This resulted in overpopulation that exceeded the city's capacity, as there was an excess demand for infrastructures, public utilities, and services, which led to the deterioration of the urban environment. Being in the delta plain of the Chao Phraya River, Bangkok is prone and vulnerable to flooding from rises in sea levels. In 2011, Bangkok faced severe flooding during a monsoon in suburban areas and the city's outskirts, especially in the western parts. Even the inner city was impacted by flooding (Bangkok Metropolitan Administration, 2013). The damage to economic and community well-being caused severe disruption to businesses, the manufacturing supply chain, and urban livelihoods. Bangkok land use is dominated by rapid urbanization. The density of high-rise buildings and the population is higher in the inner city centre than in the outskirts. A change from other types of land use to urban has been evident during the last three decades, stretching from the city centre to the suburbs in the eastern and western directions.

1.2. Hanoi

Being the capital city of Viet Nam, Hanoi covers 3,358.6 square kilometres, which is the second-largest city in Viet Nam with over eight million residents within the city area and an estimated population of 20 million within the metropolitan area. In general, the terrain gradually lowers from the north to south and from the west to east, with an average height ranging from 5 to 20 metres above sea level. Hanoi features a warm, humid subtropical climate with plentiful precipitation, making the city highly vulnerable to water-related extreme events such as floods, especially from the overdevelopment of floodplains. Hanoi, a large urban area, has the most rapid urbanization of Viet Nam. The urban area occupies 30% to 32% in 2010 and will reach 55% to 65% in 2030. Within a short time frame, the rapid urbanization process has brought tremendous change, especially in terms of the city's land-use/land cover characteristics. The inconsistent conversion of land-use/land cover of Hanoi has led to changes in land surface temperature. Therefore the response to climate change and adaptation has been identified as one of the crucial tasks that need a roadmap and plans for implementation.

This study aims to explore climate and land use projection and compare urban water demand, including adaptation plans in Bangkok and Hanoi.

2. METHODOLOGY

2.1. Downscaling of climate data

The projected future climate in 2050 in the present study is extracted using the Global Climate Model (GCM) data of HadGEM2-ES at RCP 4.5, produced by the WorldClim database with a 30-second spatial resolution (0.86 square kilometres at the equator) in Bangkok and Hanoi. The climate projection from GCM is downscaled and calibrated (bias-corrected) by using the interpolation technique. Mean temperature, maximum temperature, minimum temperature, and precipitation are projected for 2050 (average for 2041 to 2060) and compared to baseline observation data from 1960 to 1990.

2.2. Land-use modelling

The future socio-economic change in both cities is projected using scenario-based modelling. CLUMondo software was used to model the land-use change in 2050. Three main components are prepared as inputs for CLUMondo; land-use conversion, the logistic regression coefficient of the driving factors, and land-use demand. Three future LULC scenarios were analyzed based on business as usual and the green growth scenarios. A comparison of 2050 land use in Bangkok and Hanoi is conducted using the baseline year in 2013 with 400 metres resolution

2.3. Water resource assessment

Water resource assessment is projected to evaluate the urban water resources by using water flow, urban & agriculture demand site, population and water use rate in both cities. The water evaluation and planning system (WEAP) is an adaptable water resource planning model that is scalable depending on the system's complexity under investigation and can simulate water allocation policy. The advantage of the WEAP is its reliance on developing scenarios that allow the import of Geographic Infor layers into analysis with basic GIS operations, such as overlays. Each city has three input parameters into WEAP: water supply and demand, water and wastewater infrastructure and climate. Integrated analysis of climate, LUCC, and the water system for assessing urban water demand and supply was conducted to assess the water availability in the two cities.

3. RESULTS AND DISCUSSION

3.1. Climate projection for 2050

Annual precipitation, mean temperature, and maximum and minimum temperature are projected and compared with baseline climate data (1960 to 1990).

3.1.1. Bangkok

The projection of mean monthly temperature, maximum temperature, minimum temperature, and annual rainfall for 2050 for Bangkok is illustrated in Figure 1.

Temperature increases in Bangkok are expected to be within the range of 2.0 °C to 2.4 °C by 2050 in comparison to 1960 to 1990, including mean monthly maximum and minimum temperatures.

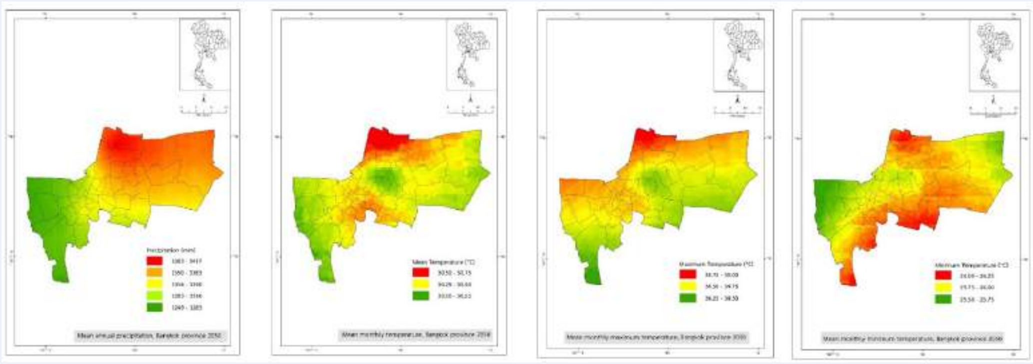

FIGURE 1. Climate projection for Bangkok for the year 2050.

However, precipitation is projected to decrease by 2050 slightly.

3.1.2. Hanoi

The projection of mean monthly temperature, maximum temperature, minimum temperature, and annual rainfall for 2050 for Hanoi is illustrated in Figure 2.

Climate change scenarios consider the change of climate variables in the middle of the 21st century (2050), such as temperature (maximum temperature (°C), minimum temperature (°C)), and rainfall (monthly rainfall). Downscaled climate data revealed a slight increase in precipitation. Warmer temperatures are expected to increase with drought spells. Greater evaporation, particularly during the summer and fall, could exacerbate drought conditions and increase the risk of wildfires.

A comparative study reveals that the pattern of rainfall change for 2050 in Bangkok and Hanoi is quite similar in terms of increasing temperature that can cause severe drought and heatwave, as indicated by Costa et al. (2015) and Guerreiro et al. (2018) . However, the increase in Hanoi's temperature is slightly higher than in Bangkok, as shown in Table 1 below.

3.2. Land-use projection in 2050

Land-use in 2050 is projected by involving two scenarios: business as usual (BAU) and green growth (GG) scenarios. Physical and socio-economic driving forces, distance to transportation networks and streams, and population density have been used to ascertain the relationship between land use and driving forces through logistic regression. Conversion resistance is one of the specific settings to determine the temporal dynamics of a simulation (Eitelberg, Vliet, & Verburg, 2015).

3.2.1. Bangkok

BAU tends to be driven by higher demands for urban expansion when compared to GG scenarios. The GG scenario encourages the conservation of existing urban green space by minimizing urban expansion in comparison with BAU. A comparison between 2013 land use and 2050 projected land use for the GG scenario is shown in Figure 3 below.

Projected urban land use for BAU and GG in Bangkok in 2050 is increased by 4.8 and 3.1 percent, respectively. The rate of urban expansion for BAU is greater than that of GG scenarios due to urban sprawl and socio-economic development during the last decades.

3.2.2. Hanoi

For the BAU scenario, most agricultural and miscellaneous land is converted to urban land with a significant agricultural land proportion. The GG scenario seems to increase the natural assets to provide the resources and environmental services on which the city relies. A comparison between 2015 land use and 2050 projected land use for the GG scenario is shown in Figure 4.

A projection of urban land area for 2050 is increased by 4.2 and 2.4 percent, respectively, compared to 2013. The urban expansion rate for the GG

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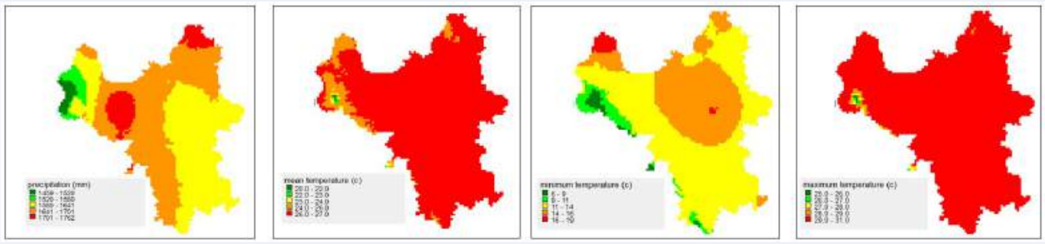

FIGURE 2. Climate projection for Hanoi for the year 2050.

Climate parameters	1960-1990		2050	
	Bangkok	Hanoi	Bangkok	Hanoi
Annual precipitation (mm)	1,445	1,689	1,337	1,645
Mean monthly temperature (°C)	28.0	23.7	30.3	26.3
Mean monthly maximum temperature (°C)	32.4	27.3	34.6	30.1
Mean monthly minimum temperature (°C)	23.6	20.1	26.0	22.5

TABLE 1. A comparative study of climate projection for 2050 for Bangkok and Hanoi.

FIGURE 3. A comparison between 2013 and 2050 Bangkok land-use for BAU and GG scenarios.

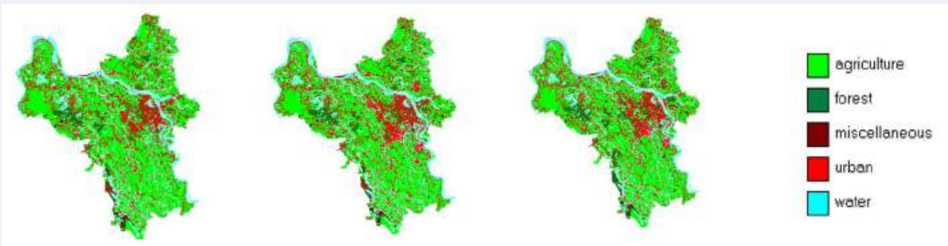

FIGURE 4. A comparison between 2015 and 2050 Hanoi land-use for BAU and GG scenarios.

scenario is lower than those of the BAU scenario due to sustainable development goals (SDGs) promoted by the United Nations.

3.3. Water resources assessment

Water resources in cities have been estimated by assessing urban water demand for different activities.

3.3.1. Bangkok

Water demand in Bangkok comes mainly from domestic uses, agriculture activities and small and medium businesses (SMEs). The future water demand tends to increase with the increase in the population due to urban growth in 2050. The top priority for water use is domestic supply, which is having the highest demand, followed by agriculture. Therefore, city planners need to carefully look at effective planning and management under the projected decrease in precipitation and increase in urban expansion. As a result of the 2050 projection, Bangkok will probably face more frequent and more intense floods and heatwaves.

3.3.2. Hanoi

Demand for water in Hanoi for domestic supply remains the highest in 2050 due to continuing increase in urban expansion, followed by industrial parks in the city's major centres and agriculture. As a result, a careful urban plan and policies need to be developed to meet those demands. Based on the results obtained from the water balance calculations developed for the study area for the 2050 scenario, the watershed will still face many difficulties in terms of distributing and supplying water for domestic, agriculture and industrial use. As a relatively large basin, agriculture is the main activity in the river basin, resulting in high demand for water use. However, water resources in the basin are unevenly distributed over space and time, which causes significant difficulties in distribution works and water use.

Both land use projections indicate a similar pattern of future urban growth in both Bangkok and Hanoi, which can affect the increase in water demand and land requirements. As stated by Pageler (2009), the increase in the number of urban dwellers can lead to higher future urban water use and cause a water crisis in case of mismanagement plan and practice.

3.4. Adaptation

3.4.1. Bangkok

There are many challenges to Bangkok in terms of adaptation regarding two crucial factors. The internal factors include population growth, labour migration, overconsumption, economic growth and competition, and capitalization trends. Many external factors influence Bangkok in various aspects, such as technological change, globalization and climate change. These factors significantly impact the environment, e.g., air pollution, solid waste, water pollution, lack of green space, and flooding and coastal erosion. The situation of the rise in the sea level in 2050 is expected to affect Bangkok, becoming far more severe than the current situation. Several measures, such as flood management and drainage infrastructure improvement, and natural buffers and early warning systems, are applied to improve the flood management system.

Furthermore, good coordination among city planners and committees for the upper river basins, such as the Chao Phraya and Tha Chin river basins, is essential to secure a sufficient amount of water for the domestic supply in Bangkok. Although the agricultural land in Bangkok will tend to decrease by 2050 dramatically, drought spells, along with seawater intrusion, might affect Bangkok in terms of water quality and availability. Additionally, urban runoff can be reduced by increasing green spaces, parks and urban wetlands, which can be effective adaptation strategies. This will enable more rainfall to soak into the underlying soil, which will help combat the occurrence of urban flooding.

3.4.2. Hanoi

As a rapidly growing metropolis, the urbanization process has decreased agricultural land and a subsequent increase in residential, industrial, and commercial land. Both projected climate change and land-use/cover change have an impact on water resources. Therefore, adaptation to climate change and land-use/cover change on streamflows within river basins has become necessary in the hydrology and water resource fields. Despite having the essential water management and climate change adaptation plans to lessen the impacts of water security in the future, these plans cannot be expected to counter the effects of a warming climate. The risk of experiencing water shortages limits the effectiveness of local solutions, such as acquiring more water from neighbouring counties or basins since many other localities will attempt to control the same resources. Many infrastructure-based solutions have been proposed for flood protection in Hanoi, i.e. strengthening the dike system in order to protect the right bank of the Red River, relocating houses and construction to areas with reduced flood risk, building upstream water reservoirs to control the pressure of floods, and strengthening flood discharge and construction. Hanoi's city planners have to find a fair balance between economic growth and the competitiveness of the city on the one hand

and the protection of its natural wealth and built environment on the other.

4. CONCLUSION

Bangkok and Hanoi are among the growing metropolises with the most rapid urbanization in Southeast Asia. This process has led to a decrease in agricultural land and subsequently increasing residential, industrial, and commercial land, resulting in more vulnerability to flooding, both in frequency and intensity. Based on the 2050 projection, climate impacts are expected from a slight decrease in precipitation and an increase in average temperature, which can lead to more frequent heavy rain due to the increase in water vapour in the atmosphere, making extreme water-related weather events stronger than before. The interaction between land-use change and hydrological responses is a complex phenomenon. In this study, urban expansion in both cities is expected to be increased by 2050, affecting the increase of water demand and land requirement in the Chaophraya river basin (Bangkok area) and the Nhue Day river watershed (Hanoi area).

The results reveal that the increase of built-up land and a rapid urbanization rate will significantly affect urban water resources in terms of higher water demand regarding domestic use, agriculture and industrial activities. Urban sprawl in 2050 could be the main cause of land subsidence in Bangkok and Hanoi at present and can worsen some impacts from climate change, i.e. urban flooding, coastal inundation and seawater intrusion. When considering both climate and land-use change in Bangkok and Hanoi in 2050, the increase in temperature is more prominent than precipitation. The combined impact of rising temperatures and urban sprawl may lead to an urban heat stress problem. Thus, urban planners and policymakers should consider their significant impacts and prepare cities for a changing climate. This preparation must be instituted by implementing effective adaptation strategies to integrate climate, land-use, and water resources into the mitigation and adaptation strategies in the short-term and long-term city development plans.

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Evaluation of prospects and barriers of biogas produced from livestock waste towards sustainable development and adaptation to climate change in Nghe An province, Viet Nam

Thu-Nga Do [a] [*], **Thi-Thoa Le** [b], **Ngoc-Bao Pham** [c], **Duc-Truong Dinh** [d], **Duc-Huu Nguyen** [a], **Wilawan Khanitchaidecha** [e]

[a] Electric Power University, Hanoi, 11900, Viet Nam
[b] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Hanoi, 11600, Viet Nam
[c] Institute for Global Environmental Strategies (IGES), Hayama, 240-0115, Japan
[d] National Economics University, Hanoi, 11700, Viet Nam
[e] Naresuan University, Phitsanulok, 65000, Thailand
[*] *Corresponding author. Email: dothu_nga2005@yahoo.com.*

ABSTRACT

The livestock sector is one of the fastest growing agricultural subsectors in Viet Nam, resulting in growing demand to sustainably dispose or re-use livestock waste. This research examined the current adoption of biogas digestion of livestock waste treatment at household farms in order to provide insights for policy towards effective implementation. A questionnaire survey was conducted in September 2019, with the participation of 120 livestock owners in Nghe An province, which focussed on accessing their perspectives on biogas and examination of factors impacting their decisions to utilize this technology. Most respondents determined biogas to be an attractive solution for improving the environment. However, several factors limited the development of biogas installation, including technical and financial barriers, awareness and capacity limitations, and financial support as the most significant of these. Government support and policies that encourage household biogas utilization as a sustainable energy source to combat climate change is recommended.

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KEYWORDS
Energy security, water safety, waste management, greenhouse gas emission reduction, Nghe An province, pig production

HIGHLIGHTS

- All respondents were aware of the negative impacts of untreated livestock waste.
- The average volume of household biogas digesters has increased in recent years.
- Large volumes of biogas are wasted due to low quality biogas devices.
- Only 35% of respondents use bio-slurry for crop fertilization.
- Lower livestock prices reduce the demand for biogas installation.

1. INTRODUCTION

The livestock sector plays a dominant role in the Vietnamese agriculture industry, accounting for 28% of agricultural gross value (Tung, 2017) and is one of the fastest growing subsectors. According to the General Statistic Office, Viet Nam's main livestock included 28.15 million pigs, 5.80 million cows and 2.43 million buffaloes by the end of 2018 (GSO, 2020). Further, smallholders contribute significantly to this growth. Approximately 80% of Viet Nam's pig herds are currently owned by smallholders and this number is expected to remain competitive in the future (Lucila et al., 2012). In 2017, pig production from smallholders contributed 5.5% to the national GDP (MARD, 2016).

Nghe An, Viet Nam is a typical livestock-oriented province, contributing 47% of the total provincial agricultural production in 2019 (Nghe An GSO, 2019). Provincial reports indicate increasing pressure to handle livestock waste sustainably (Nghe An PC, 2015), with several incidences of water pollution attributed to poor livestock waste disposal. For instance, industrial-scale pig farm waste caused severe water quality degradation of the Trang Den Lake in Nam Dan district linked to the Dai Thanh Loc Limited Company (Dac, 2020). Lake water turned black, alongside reports of strong odours from the pollution of pig slurry. Another example from Do Luong district reported damage to 142,000 m^2 of rice land, 42,000 m^2 of fishponds and contamination of drinking water in 16 households in the commune attributed to the waste effluent from the large-scale pig-breeding farm of Thai Duong Limited Company (Hoan, 2011). Consequently, several solutions have been applied in the province to increase the protection of surrounding environments from untreated livestock waste, including biogas digesters and compost pits. Recovery of biogas from livestock waste is not only a method to obtain a local source of energy but can reduce greenhouse gas (GHG) emissions related to waste management, fossil fuel and chemical fertilizer usage. However, the application of biogas from livestock waste is still limited (Nghe An PC, 2015). The National Energy Master Plan, which aims to prioritize the development of renewable energy sources for electricity production, also stated that the greatest difficulty in developing biogas digestion in Viet Nam is inadequate interest and awareness of livestock farmers and society about the role and benefits of biogas (MOIT, 2017). Additionally, mobilizing people to use a new type of energy is very difficult with routine use of energy from electricity or traditional materials (e.g., coal and/or wood).

Due to its agricultural landscape, Nghe An province was selected as a case study to examine the current situation of adopting biogas digestion for livestock waste treatment in household farms in order to identify challenges, knowledge gaps and insights for policy. To achieve this, a questionnaire survey was conducted to (i) evaluate the biogas potential of the province regarding the reduction of

GHG emissions and its development as a renewable energy source; (ii) assess household perspectives on using biogas digestion for livestock waste treatment; and (iii) highlight factors that impact household decisions to adopt biogas technology.

2. METHODOLOGY

2.1. Description of the study site

Nghe An province is located in the North Central Coast of Viet Nam, with an area of 16,490 km^2, accounting for 32% of the total area of the North Central Coast region and 4.98% of Viet Nam. Land-use is comprised of 75.8% agricultural land, 7.8% non-agricultural land and 16.4 % unused land. In 2019, the population was estimated at 3.3 million inhabitants (Nghe An GSO, 2020). The province has 17 districts, 3 towns and a city, stretching from the high mountainous districts of Ky Son, Tuong Duong to delta districts of Dien Chau, Quynh Luu (coastal) (Figure 1).

FIGURE 1. Location of the survey in Nghe An province, Viet Nam.

Livestock is an important and growing sector in Nghe An province, with the recent growth rate of livestock numbers estimated to be 5% to 5.5% per year. The province has more than 500,000 households producing livestock and poultry (Nghe An GSO, 2019). As of May 2019, total buffalo and cow numbers were estimated at 272,970 and 471,029 heads, respectively. While the total herd of pigs were two-fold higher, at 857,490 heads.

2.2. Questionnaire survey

In September 2019, a questionnaire survey was conducted of 120 livestock households from three neighbouring districts of Nghe An province: two delta districts (Dien Chau and Quynh Luu) and one middle mountainous district (Nghia Dan). Trained investigators visited each district and carried out personal interviews with randomly selected households, rather than requesting that respondents complete the surveys on their own. This methodology was chosen on account of the higher accuracy of responses and completion rates compared to the latter. The questionnaire survey focused on the perspectives of households on using biogas digestion for livestock waste treatment and their knowledge on the benefits of biogas technology. Identifying factors that influence household decisions to adopt biogas technology were also included.

3. RESULTS AND DISCUSSION

3.1. Prospects of biogas produced from livestock waste for GHG reduction and renewable energy

Pig populations in Nghe An province have seen a slight reduction over recent years due to pig disease outbreaks and an increase in the cost of feed and other inputs (Figure 2) (Nghe An PC, 2015). The pig population recovered in 2018 but dropped again in 2019 due to African Swine Fever (Le et al., 2019). The decrease in pig population was 3.4% annually between 2010 and 2017 but dropped to 17.6% during the disease outbreak of 2018-2019. Interestingly, the highest number of biogas digesters installed was between 2016 and 2018, as pig numbers increased.

Biogas potential from livestock waste in Nghe An province previously reported by Le, Do, and Dinh (2021) was estimated to emit 3,000 to 5,300 tCO_2 per year if no waste treatment was applied. These values were estimated using the annual values of pig manure generated in the province (~2,100-2,900 thousand tonnes from 2010 to 2019). With the current biogas adoption shown in Figure 2, a reduction of 75% of emissions could be achieved, equal to 2,200 to 4,000 tCO_2 per year, and a potential biogas

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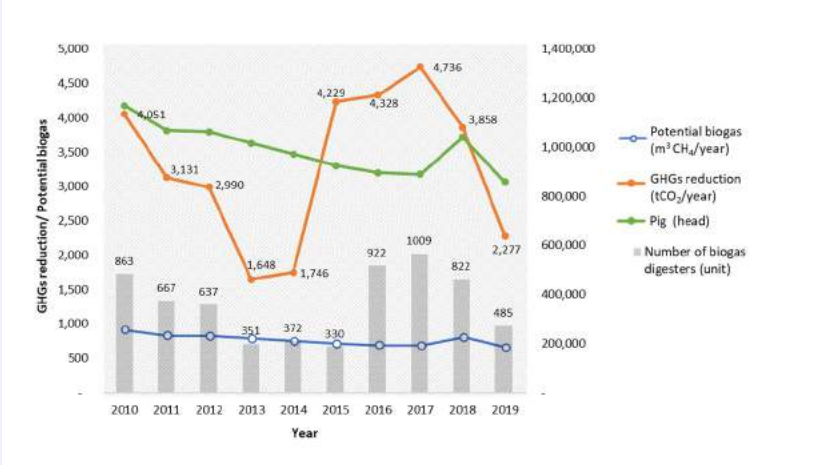

FIGURE 2. Trend of biogas potential and GHG reductions by adopting biogas in Nghe An province from 2010-2019.

load of 700-900 $m^3 CH_4$ could be produced (SNV, 2021). Thus, biogas digestion could not only reduce environmental pollution problems but GHG emissions too, via the production of cleaner energy.

3.2. Status quo of biogas usage in districts of Nghe An province

In general, pig production in Nghe An province can be divided into industrial and smallholder farms. Industrial farms have at least 20 sows or 100 fatteners, and heavily invest in production, whilst smallholder farms operate on a much smaller scale (i.e., 1-9 heads). In 2015, there were 174 industrial farms located mainly in the delta districts, which jointly kept about 30% of the total pig herd of the province (Nghe An PC, 2015). The remaining 70% of the total pig herd belongs to smallholder farms (households), which are more vulnerable to swine diseases due to less hygienic farmyard conditions due to inadequate slurry removal. Biogas utilization could be an effective solution for smallholder farms to cope with this issue.

The delta districts had the highest number of biogas digesters of the different districts, whereas the high mountainous districts had the lowest (Figure 3). The ratio of biogas to pigs in the delta districts was also higher compared to the moutainous districts, which could be due to the higher pig population in the delta districts accounting for 54.5% of total pig numbers in the whole province (Nghe An GSO, 2019).

Dien Chau district has the largest number of biogas digesters in the province. This number is two-fold higher than Do Luong and Quynh Luu districts, which have the second largest, with all three located in the delta area. It is important to note that Dien Chau district has not only the biggest amount of biogas, but also the largest ratio of biogas to pig numbers. Even Cua Lo town has one of the largest ratios of biogas to pig number, despite a small number of biogas digesters. Thai Hoa town located in the middle mountainous area, has the second largest ratio of biogas to pig numbers amongst districts in Nghe An province.

3.3. Questionnaire survey of livestock farmers

3.3.1. Characteristics of the livestock households

The response rate of the questionnaire survey was 100%. In total, the team collected primary data from 120 individuals comprising 78 females and 42 males. This number implies that women are the main labour source in the countryside. An average number of members in a household are between 4 and 5 people, with 2 to 3 people (82.5%) accounting for the labour workforce. The ages of respondents ranged between 23 to over 60 years old, with the largest group falling between 31 and 60 years old (64%). The educational level of respondents ranged from primary school to high school, with a few possessing undergraduate degrees. More than

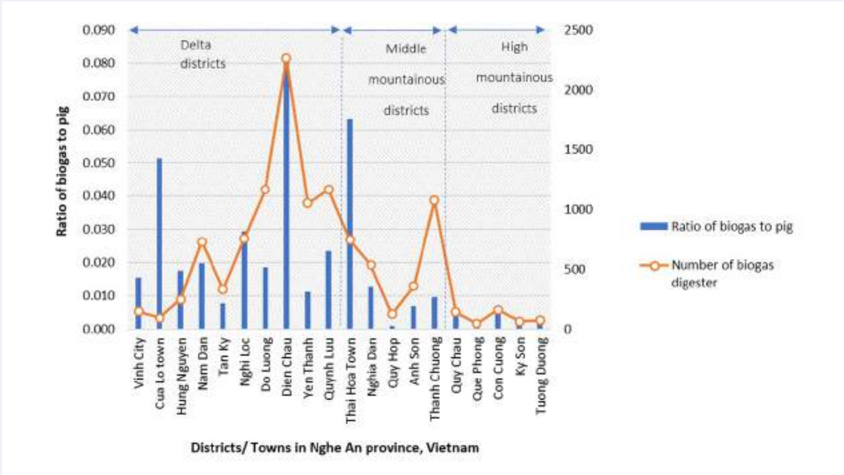

FIGURE 3. Number of biogas digesters (orange line) and the ratio of biogas to pig numbers (blue bars) in various districts of Nghe An province Nghe An GSO (2020).

10% of respondents received a primary degree. Survey results indicate the main income from biogas households was from cultivation (35%), followed by service-trade and business (34%) and lastly from livestock raising mainly pig production (31%). Monthly household income ranges from 2 million to over 10 million VND, with 39% of respondents earning 2–4 million VND, and 31% earning 4–6 million VND. Twenty-eight households had a monthly income of over 6 million VND, and only three of them an income of over 10 million VND.

3.3.2. General information of the installed biogas digesters

From 2003 to 2019, 72.5% of biogas digesters were built in 2014 (Figure 4). The average construction cost per m^3 of digestion capacity gradually increased from 884,000 VND in 2003 to 1,407,000 VND by 2019. This increase was caused by the rise in costs of construction materials and labour. In addition, the selection of biogas digester capacity has to follow the Sectored Standards guideline (MARD, 2006), causing increasing costs of biogas digester capacity. With coverage of 6.9 m^3 in 2003, 13.5 m^3 in 2015, then 14.5 m^3 in 2019, this undoubtedly resulted in the steady increase of installation costs per unit.

In contrast, the financial support of 1 million to 1.2 million VND per digester construction from the Government of Viet Nam (GoV) and the Netherlands Development Organization (SNV) project (SNV, 2021) has not changed over the past few years. Ninety-six point seven percent of the 120 households received financial support but four households (3.3%) had to pay for the construction cost themselves (about 10-15 million VND). Considering the monthly income of most respondents (from 2-6 million VND), installation is an extravagance. Household decisions to adopt biogas digester installation with no or minimal support stemmed from either complaints regarding livestock waste, and recommendations or experience from other households with biogas digesters as to their benefits.

3.3.3. Perspectives of households using biogas digestion for livestock waste treatment

Most respondents determined livestock and domestic waste to be the two main pollution sources in their hometown. They were aware of the negative impacts on human health and living conditions from attending training courses organized by the GoV (MARD, 2016). Most respondents agreed that biogas digestion was a good solution to ensure environmental hygiene when rearing livestock. They experienced benefits such as saving on fuel costs and reducing smoke production from cooking by switching to biogas technology. However, more than half experienced difficulty during operational and maintenance (O&M) stages. This highlights that

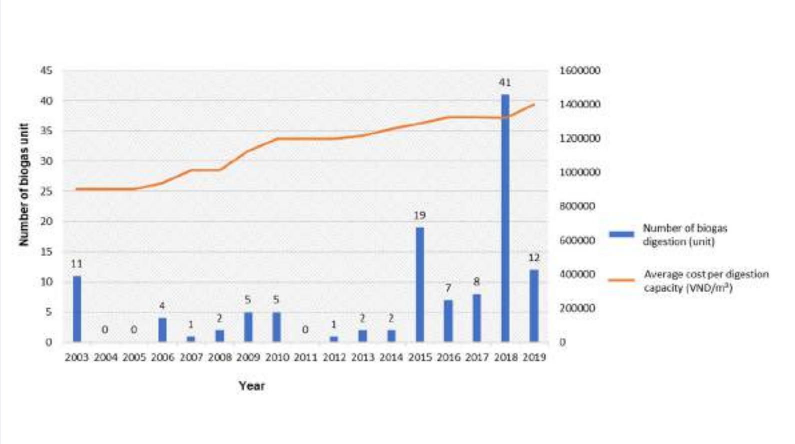

FIGURE 4. Number of biogas and average cost per volume construction.

encouraging farmers to adopt biogas technology requires improvements to follow-up services to ensure the sustainable utilization of this practice. Studies by (Roubík, Mazancova, Banout, & Verner, 2016) and (Vu, Tran, & Dang, 2007) reach similar conclusions in other parts of Viet Nam.

Most respondents used biogas for cooking only (95%), with only a small group using biogas energy for both cooking and lighting (5%). Typically, most biogas cooking devices are handmade or not brand-named, with inefficient burning of cooking stoves leading to large volumes of gas wasted. As described in a study in Hue City and Hanoi Capital, Viet Nam, the biggest problem found on farms was the low quality of biogas devices. Gas cookers rusted very quickly and were unusable after 2-4 years (Cu et al., 2012).

Seventy-four respondents (61.6%) supplied surplus biogas (if any) to their neighbours; whereas the remaining 35.8% burned off excess biogas or released the gas into the atmosphere (2.6%). It is important to note that respondents expressed their interest in using surplus gas to power electricity generators.

The residue of biogas digestion, bio-slurry, can be used as fertilizer for crop production and aqua-culture. Nutrients in bio-slurry, especially nitrogen, are more readily available than in manure, leading to a larger short term fertilization effect. However, only 35% of respondents use this by-product of biogas digestion for crop fertilization because they have backyard or cultivated land nearby. 65% of respondents do not use the by-product because they either doubt the benefits (25%), have no cultivated land (30%) or have difficulty in transporting liquid biogas slurries (10%). Similar findings reported that 33% of surveyed farmers used solid parts of digestate as fertilizers for rice, and the use of liquid parts was very limited due to long distances between biogas digestions and rice fields (Hynek, Jana, Le, & Jan, 2018). From the perspective of farmers, a lack of transport vehicles/devices were considered primary barriers of bio-slurry utilization, which was also confirmed in other studies in Viet Nam (Vu, Vu, Jensen, & Sommer, 2015), Tanzania (Jackson & Mtengeti, 2005) and Uganda (Bos & Kombe, 2009).

3.3.4. Examine the barriers of biogas development and solutions to overcome the issues

Most households (78%) declared positive impacts from biogas adoption. The investment cost followed by livestock population were the most important factors influencing the decision of livestock owners to install biogas digesters. Other factors, such as availability of land for biogas digester construction, the type and size of livestock, the benefits in pollution reduction and production of energy also contributed to farmers' decision-making, significantly. This statement is also recognized in many rural areas in Viet Nam (Cu et al., 2012) and in Cambodia (Phanthavongs & Saikia, 2013). Few households admitted that the financial contribution from the GoV of 1 million to 1.2 million VND per biogas digester construction was necessary. However, delays in cash delivery and discrepancies between amounts received across different households were reported. Notwithstanding, this financial support is more meaningful to lower income households, contributing significantly in decisions to install biogas digesters. Besides, this amount needs to be increased to match increasing construction costs. Finally, the questionnaire survey suggests that biogas digester development and its application were heavily dependent on prices of livestock products. When prices for products go down, there is a tendency to reduce or halt livestock production, thus, reducing the demand for biogas digester installation.

Barriers encountered in household biogas development include technical, financial, awareness and capacity limitations (Dinh et al., 2021). Technical support is very important for the O&M stages of biogas digestion (ADB, 2016). Development of technical assistance will help in ensuring the quality and safety of constructed biogas digesters. Additionally, the GoV should develop testing procedures and standards for biogas technologies to improve their productivity and reliability. Government policies are important in driving changes to farmers behaviour in waste management and for encouraging private investments (DLP-MARD, 2016). For instance, alongside subsidies, the GoV should further use its tax policy to encourage investments in biogas technologies (for example introducing reduced import taxes and partial exemption from value-added tax of biogas equipment). Training courses for livestock owners should also cover the update of policies and regulations, as well as sharing successful biogas models, and how to overcome technical barriers in order to convince farmers to use upgraded biogas technology (MOIT, 2017). Institutional capacity building should include the dissemination and update of policy measures to maintain transparency and credibility of governance, and targets to increase the sources of financial support for new biogas digester installation, perhaps through attracting new potential domestic investment (ADB, 2016).

4. CONCLUSION

In Viet Nam, the livestock sector has grown rapidly in recent years, resulting in challenges to the handling of livestock waste. Encouraging livestock households to construct biogas digestors is one solution to manage livestock waste, whilst reducing GHG emissions, producing renewable energy, and creating by-products that can be used as organic fertilizers. The questionnaire survey in Nghe An province has highlighted limiting factors to the uptake of livestock waste biogas. Addressing these factors are necessary to upgrade and promote biogas utilization as an effective and costly means toward sustainable agricultural production and climate change mitigation.

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Climate resilience of farming systems in steep mountain terrain of selected regions in South Asia

Thusitha Bandara[a], **Buddhi Marambe**[b *], **Gamini Pushpakumara**[b], **Pradeepa Silva**[b], **Ranjith Punyawardena**[c], **Sarath Premalal**[d], **Lasantha Manawadu**[e], **Khem Raj Dahal**[f], **Md. Giashuddin Miah**[g]

[a] Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka
[b] Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka
[c] Natural Resource Management Center, Department of Agriculture, Peradeniya, Sri Lanka
[d] Department of Meteorology, Colombo, Sri Lanka
[e] Faculty of Science, University of Colombo, Colombo, Sri Lanka
[f] Department of Agronomy, Tribhuvan University, Kathmandu, Nepal
[g] Department of Agroforestry and Environment, Bangabandhu Sheikh Mujibur Rahman University, Dhaka, Bangladesh
[*] *Corresponding author. Email: bmarambe@pdn.ac.lk.*

ABSTRACT

This study assessed the climate resilience and characterized the existing farming systems in steep terrain in the hilly regions in South Asia. The farming systems considered were at an elevation ≥300 m in the mountain regions of two sites from Sri Lanka (Hatton and Welimada) and one site each from Bangladesh (Chittagong) and Nepal (Jhikhu Khola). A Climate Resilient Index (CRI*i*) score, varying from 0 (negligible resilience) and 1 (very high resilience), was calculated for each household using 31 parameters under Adaptive Capacity (ADC), Absorptive Capacity (ABC) and Transformative Capacity (TC). To spatially represent the CRI*i*, the four study locations were mapped using Inverse Distance Weighted (IDW) interpolation technique of GIS. All 424 households in the study sites scored a CRI*i* between 0.36 and 0.76, while the average CRI was the highest in Hatton (0.67), followed by Welimada (0.60), Jhikhu Khola (0.59) and Chittagong (0.48). Different demographic, socioeconomic and environmental parameters have contributed to the level of climate resilience of farming system units. Identification of good management practices of the climate-resilient farming systems and implementing those practices in vulnerable systems would increase the resilience and well-being of farming communities in steep terrain of mountain regions in south Asia.

KEYWORDS

Climate resilience, farming systems, hilly areas, steep terrain, South Asia

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HIGHLIGHTS

- Adaptation capacity of farming systems mainly determines their climate resilience.
- Climate Resilience Index (CRI) of farming systems varies with geographical origin.
- CRI is an effective tool to decide on a sustain- able solution to combat climate change.

1. INTRODUCTION

Changing climate with extreme and unpredictable weather events has significant impacts on regional, national, and local developmental efforts. With added challenges to the developing countries in their development interventions, the impact of climate change goes beyond specific sectors, geographic areas, communities and ecosystems. The agricultural or farming systems are extremely vulnerable to climate change (Pound, Lamboll, Croxton, Gupta, & Bahadur, 2018) as they are sensitive to variations in temperature, precipitation and occurrence of natural events and disasters such as droughts and floods, thus, directly impacting the economy, food security and development. In South Asia, most of the population is predominantly dependent on agriculture as a source of livelihood. Mountain environments in South Asia, especially the steep terrain areas, appear among the most severely affected ecosystems, where any change in temperature and precipitation patterns at all scales would result in serious impacts on such ecosystems (Fort, 2015). Therefore, mountain agriculture is increasingly vulnerable to climate change (FAO, 2019).

Mountains occupy 22% of the world's surface, and 1/3 of the world's mountains are found in Asia. With a vast area of the land surface, developing an efficient agriculture or farming system for mountain areas is vital and has become a frequent topic of concern (FAO, 2019). This is especially due to the livelihood of large segments of mountain populations depends heavily on agriculture. However, several constraints, including undulating topography, small fragmented and scattered land holdings with limited use of inputs, high proneness to soil erosion and degradation due to slope, shallow and stony soils subjected to periodic water stress, rainfed agriculture, and natural hazards, make agriculture in steep terrain a challenging task (Fatima & Hussain, 2012). Hence, there is a need for an integrated, multidisciplinary and holistic approach to address those issues to improve the climate resilience, livelihoods of mountain people and to reverse the declining trend of productivity and loss of biodiversity in the traditional mountain ecosystems (Li, Solh, & Siddique, 2019).

Building climate resilience in production systems is required to sustain agricultural productivity (Marambe et al., 2015; Aryal et al., 2020)and to minimize the impacts on existing and future food production systems (Gregory, Ingram, & Brklacich, 2005; Schmidhuber & Tubiello, 2008; Tran, Tran, & Tuan, 2012). Adaptation is recognized as important in reducing vulnerability or increasing resilience to climate change (Engle, Bremond, Malone, & Moss, 2013; Mendelsohn, 2008; Marambe et al., 2018). Decision-makers and development practitioners need to understand the climate vulnerabilities in order to reduce the potential impacts of climate change on the people, sectors, and places that they care about (USAID, 2016). Therefore, there is a growing need for approaches and concepts to assess climate vulnerability, adaptation and resilience and to monitor the progress in achieving resilience at the national, sub-national and regional levels (Welle, Witting, Birkmann, & Brossmann, 2014). Though there are many studies on assessing the agriculture systems for climate resilience (Speranza, 2010; Tui, Descheemaeker, Masikati, Valdivia, & Antle, 2016; Bizikova, Waldick, & Larkin, 2017) only a limited number of studies (Fort, 2015; Chitale, Gibert, Bhuchar, Capizzi, & Ling, 2017; Lama & Devkota, 2009; Tsering, Sharma, Chettri, & Shrestha, 2010) have focused on the hilly areas, especially the steep terrains.

Identification of the best-suited farming practices, which could be recommended for steep terrains in mountain areas of South Asia to minimize resource degradation and to ensure environmental sustainability while enhancing climate resilience, was considered a vital and urgent requirement. With this broader perspective, this study attempted to evaluate existing farming practices in steep terrains in the mountain areas in three countries in South Asia and to use an indicator approach to assess their level of climate resilience. The outcome is expected to support policy formulators, stakeholders, and administrators in identifying suitable agricultural production systems in the already climate-vulnerable steep terrains in the respective countries through appropriate adaptation strategies.

2. METHODOLOGY

2.1. Site selection

Study sites were selected in mountain regions in Sri Lanka, Nepal and Bangladesh with a slope of 30% or above, located at a representative elevation range of 300 m to 1,800 m above mean sea level. The site selection was based on the availability of different farming systems such as crop, livestock and fish farming, forest, and availability of historical information on disaster for the past ten years and climate data for the past two decades. The short term data for natural disasters and climate parameters were considered based on the availability and reliability of data across sites and based on expert consultation. Further, easy access to the sites and the willingness of households in the area to support the project activity were also considered based on the initial discussion. Two sites were selected from Sri Lanka; namely, Welimada (06°56’0” to 06°57’10” N and 80°51’0” to 80°53’0” E) and Hatton (06°46’25” to 06°47’10” N and 80°42’20” to 80°43’45” E), and one site each from Chittagong in Bangladesh (which is now officially known as Chattogram; 22°07’20” to 22°09’30” N and 92°12’40” to 92°13’43” E), and Jhikhu Khola in Nepal (27°35’0” to 27°55’0” N and 85°18’0” to 85°48’0” E). The various farming systems (FS) in the study sites were characterized to support the comparison of data. Each household was considered as a farming system unit (FSU). In order to represent at least 30% of the agrarian population, 96 households from Chittagong, 103 households from Jhikhu Khola, 125 households from Hatton and 100 households from Welimada were selected for the study using random sampling.

2.2. Data collection

A pre-tested questionnaire translated into respective local languages was used to collect primary data, namely, basic information, socioeconomic characteristics, plant and animal inventory in the farming system, water and soil conservation strategies and crop management adopted in the farming system, land-use patterns in the farming system, climate change adaptation strategies in the farming system, food consumption pattern, income and expenditure of the household, market, and enumerator’s observation. A database was constructed based on survey results. Secondary data were collected for the past two decades from relevant local and national administrative services on productivity and soil erosion, soil fertility status, land degradation status, rainfall and temperature, human-health related issues, pest outbreaks in crops, and animal species reared. Data on system changes and the occurrence of natural disasters were collected for the past decade.

2.3. Analytical framework

Details in the database were initially analyzed to check the differences among four study sites and to identify the characters of different farming systems such as use of crop varieties and animal breed, resource utilization, irrigation methods, integrated farming practices, fertilizer usage, cropping pattern, pest and disease management, etc. Analysis of variance (ANOVA) was done for continuous variables (cultivated extent, age, living period, income, expenditure), and Chi-Square tests were performed using percentages and frequencies for the nominal and ordinal data in order to test the differences among four sites.

2.3.1. *Indicator approach*

The construction of an index based on specific sets or combinations of parameters, which serve as proxies, is a commonly used quantitative approach to assess climate resilience. The parameters were selected to capture the current status of the system with respect to climate resilience in selected mountainous areas.

Normalization of parameters

Parameters used in the study were measured in different scales and units. Therefore, normalization of parameters was done to obtain values ranging between 0 and 1 that are free from units and comparable. Before the values were normalized, the functional relationship between the parameters and the climate resilience were determined from previous studies or based on the theoretical assumptions as stated in Table 1.

If resilience increases with an increase in the value of the parameter (positive correlation), resilience has a positive functional relationship. Then normalization was carried out by using Equation (1), developed according to the Min-Max method described by (OECD, 2008).

$$Xij = (Xi - Min\ \{Xj\}) / (Max\ \{Xj\} - Min\ \{Xj\}) \quad (1)$$

where X*ij* is the normalized value of parameter (*j*) with respect to household (*i*), Xi is the actual value of the parameter with respect to household (*i*), and Min {X*j*} and Max {X*j*} are the minimum and maximum values, respectively, of parameter (*j*) among all the households.

If the functional relationship with resilience was negative, i.e. the resilience decreases with an increase in the value of the parameter (negative correlation), the normalized score was computed using Equation (2), developed according to the Min-Max method described by OECD (2008).

$$Xij = (Max\ \{Xj\} - Xi) / Max\ \{Xj\} - Min\ (Xj) \quad (2)$$

Climate Resilience Index

As defined by the Intergovernmental Panel on Climate Change (IPCC, 2007), climate resilience is the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the ability of self-organization, and the capacity to adapt to stress and changes. According to Welle et al. (2014), climate resilience is the combination of absorptive, adaptive and transformative capacities.

Aligning with the definition provided by IPCC, a Climate Resilient Index (CRI) was developed to assess the capacity of the community to reach and maintain an acceptable level of functioning with ongoing climate change and variability using 31 parameters. To better understand resilience, the parameters selected for CRI were aggregated into three resilience capacities: Adaptive Capacity (ADC; 18 parameters), Absorptive Capacity (ABC; 9 parameters), and Transformative Capacity (TC; 4 parameters), and their description and the hypothesized relationship with the climate resilience are presented in Table 1. In order to accomplish a good validity and provision for cross-comparison, parameters were selected based on the literature available for situations similar to the present study and expert opinion followed by correlation analysis.

Normalised parameters were aggregated into respective resilience capacities to generate the CRI usingEquation (3):

$$CRIi = (ADCi + ABCi + TCi) / (NADC + NABC + NTC) \quad (3)$$

where CRI*i* is the climate resilience score, ADC*i* is the value of adaptive capacity, ABC*i* is the value of absorptive capacity, and TCi is the value of transformative capacity concerning i^{th} household. The NADC, NABC and NTC are the number of parameters in adaptive capacity, absorptive capacity, and transformative components, respectively.

Values for ADC, ABC and TC were calculated using Equations (4), (5) and (6), respectively. Equal weight was assigned for each parameter to make it simple in approach and interpretation.

$$ADCi = \sum (ADC)ij \tag{4}$$

where ADCi is the value for adaptive capacity with respect to household (i) and ADCij is the value of the j^{th} parameter of adaptive capacity with respect to the i^{th} household.

$$ABCi = \sum (ABC)ij \tag{5}$$

where ABCi is the value for absorptive capacity with respect to household (i) and ABCij is the value of the j^{th} parameter of absorptive capacity with respect to i^{th} household.

$$TCi = \sum (TC)ij \tag{6}$$

where TCi is the value for transformative capacity with respect to household (i) and TCij is the value of the j^{th} parameter of transformative capacity with respect to i^{th} household.

Values of CRIi were calculated separately for each of the 424 households of each site and pooled to have a systems approach. Based on the maximum and minimum values of CRIi, cut-off points of the five resilience levels, namely, least, less, moderate, high and very-high, were determined using the Equal Interval Classification method (Osaragi, 2008). The percentage of households in each category was computed separately for each study site and those details were used for within site and among sites comparisons. The study sites were mapped for climate resilience based on the values calculated for each household, using the Inverse Distance Weighted (IDW) interpolation algorithm of Geographic Information Systems (GIS) to examine the spatial representation of the results of the index.

As the majority of the parameters comprised categorical data (only four parameters out of 31 parameters were continuous), the traditional Principle Component Analysis (PCA) was not used to reduce dimensionality and in finding the contribution from each parameter. Therefore, the contribution of each parameter for CRI of the respective study site was calculated based on the average contribution of the households' responses of the corresponding parameter for each study site separately. As the average value of each parameter ranged between 0 and 1, based on the equal interval classification, the parameters having average values between 0.0–0.33 were considered as least contributing, between 0.34–0.66 were considered as moderately contributing and 0.67 to 1.0 were considered as most contributing to the CRI in the respective study site.

3. RESULTS

3.1. Characteristics of farming systems

A Farming System (FS) consists of a set of organized conditions for the production of crops, livestock, fish, agroforestry, etc., and includes the procedure of using the land, labour, inputs, and capital to manage farm, household, non-farm and off-farm production, and consumption to meet its objectives and priorities under a certain physical, biological and socioeconomic conditions. The FSs varies with available natural resource base including water, land, grazing areas and forest, climate, landscape including slope, farm size, tenure and organization. Furthermore, different FSs could be identified based on the dominant pattern of farm activities and household livelihoods, including crops, livestock, trees, aquaculture, hunting and gathering, processing and off-farm activities, main technologies used, the intensity of production and integration of crops, livestock and other activities.

In all four study locations, the majority of the household heads (HHs) were males. Hatton site in Sri Lanka had the highest percentage of female household heads (21%), while it ranged from 2% to 8% in other study locations. A higher proportion of elderly HHs (≥ 65 years) were reported in Welimada (17%), followed by Hatton (12%), Jhikhu Khola (11.7%) and Chittagong (6.3%). Furthermore, more

Capacity	Components of climate resilience	Parameters selected for analysis	Description of parameters	Type of Data	Hypothesized relationship between parameter and climate resilience
Adaptive capacity	Socio- Demography	Gender of the household head	Whether the household is a male or female	Categorical (Male, Female)	Households with female head, lower the resilience (Fuller & Lain, 2019; Asmamaw et al., 2019)
		Dependent household head	Household heads older than 65 years	Categorical (Whether the household head is older than 65 years or not)	Households with dependent Household head, lower the resilience (Asmamaw et al., 2019)
		Condition of the house	Based on the construction materials of the walls, roof and the floor	Categorical	Poorly constructed houses lower the resilience (Tran et al., 2012)
	Education	Educational level	Whether the household head has completed primary, secondary or post-secondary education	Categorical (Education level: No schooling, Primary, Secondary, post-secondary)	Household heads with no formal education, lower the resilience (Abdul-Razak & Kruse, 2017)
	Economy	Property regime	Availability of own land	Categorical (Yes, no)	Households that do not own private land, lower the resilience (Roth, 2013; Ali & Erenstein, 2017; Asmamaw et al., 2019)
		Income sources	Diversified income sources	Descrete (No. of income sources)	Having more than one income source, higher the resilience (Asmamaw et al., 2019; Abdul-Razak & Kruse, 2017)
		Household employment	Whether the members of households are employed or not	Descrete (No. of employed members in the household)	Any member of household is not employed, lower the resilience (Opiyo et al., 2014; Zurovec et al., 2017; Jamshidi et al., 2019)
		Savings	Ratio of income and expenditure	Continuous (Ratio of income and expenditure)	Households with little or no savings, lower the resilience (Sverdlik et al., 2019; Botero & Salinas, 2013; Silva et al., 2018)
		Dependence on agriculture	Percentage of agriculture base income	Continuous (Percentage of agriculture base income)	Households that depend on agriculture as the major source of income, lower the resilience (Laitae et al., 2014; Botero & Salinas, 2013)

TABLE 1. The 31 aggregated parameters selected for climate resilience index with their hypothesized relationship to climate resilience.

Capacity	Components of climate resilience	Parameters selected for analysis	Description of parameters	Type of Data	Hypothesized relationship between parameter and climate resilience
Adaptive capacity	Animal Husbandry	Practising of animal husbandry	Whether the household is practising animal husbandry	Categorical (Yes, no)	Practising of animal husbandry, higher the resilience (FAO, 2020)
		*Diversity of Species	No. of animal species	Descrete (No. of animal species)	Have more than one species, higher the resilience (Rojas-Downing et al., 2017)
		*Animal breed	Whether animals are hybrid, cross bread or indigenous	Categorical (hybrid, cross bread, indigenous)	Have hybrid breeds, lower the resilience (Ahmed et al., 2013; Rahim et al., 2013)
		*System of animal rearing	Whether animals are rearing as extensive, intensive or semi-intensive system	Categorical (Extensive, intensive and semi-intensives)	Practicing of extensive system for animal rearing, lower the resilience (Rust, 2018).
		*Feeding method	Whether animals are feed with concentrate, cut and fed, free grazing or other	Categorical (Concentrate, cut and fed, free grazing or other)	Feeding animals with concentrate feeds, higher the resilience (Chaidanya et al., 2015)
	Awareness	Farming knowledge	Years of experience in farming	Continuous	lower the farming experience, lower the resilience (Abdul-Razak & Kruse, 2017)
		awareness about the area	Living period in the area in years	Continuous	lower the living period, lower the resilience (Opiyo et al., 2014)
		Climate change	Noticed the changes in climate	Categorical (Yes, no)	Having noticed the changes in climate, higher the resilience (Opiyo et al., 2014)
		Changes in farming system	Noticed the changes in farming system	Categorical (Yes, no)	Having noticed the changes in farming system, higher the resilience (Tripathi & Mishra, 2017)
	Food	food from own cultivation	Whether households consume food from animal husbandry	Categorical (Yes, no)	Consuming food from own cultivation, higher the resilience (FAO, 2015)
		food from animal husbandry	Whether households consume food from their cultivations	Categorical (Yes, no)	Consuming food from animal husbandry, higher the resilience (FAO, 2020)
	Sanitation	Improved toilets	Type of toilet	Categorical (Septic tank, sewerage system, open pit, outside land, other)	Having improved toilets, higher the resilience (Sherpa et al., 2014)

Capacity	Components of climate resilience	Parameters selected for analysis	Description of parameters	Type of Data	Hypothesized relationship between parameter and climate resilience
Absorptive Capacity	Technology utilization	Diversity of crops	No. of crops cultivated	Descrete (No. of Crops cultivated)	Having cultivated more than three crops, higher the resilience (Lin, 2011; Rojas-Downing et al., 2017)
		Cropping System	Whether cultivated as sole crop or mixed cropping	Categorical (Sole crop, mixed crop)	Cultivated as sole crop, lower the resilience (Lizarazo et al., 2020)
		Cultivated variety	Cultivated variety	Categorical (Hybrid, local)	Cultivated hybrid varieties, lower the resilience (Negi, 1994; Abewoy, 2018)
		Fertilizer management	Type of fertilizers used in the cultivation	Categorical (Organic, inorganic, both organic and inorganic)	Using organic fertilizers, higher the resilience (Niles, 2008; Müller, 2009)
	Irrigation Potential	Cultivation under irrigation	Sources of water for agricultural activities	Categorical (Rainfed, irrigated, both rainfed and irrigated)	No potential for irrigation, lower the resilience (Abdul-Razak & Kruse, 2017)
	Ecological Stability	Presence of naturally grown plants	No. of naturally grown plants available	Descrete (No. of naturally grown plants available)	Presence of naturally grown plants, higher the resilience (Cleland, 2011)
		Presence of woody trees	No. of woody trees available	Descrete (No. of woody trees available)	Presence of woody trees, higher the resilience (Akinnagbe & Irohibe, 2015; Mosquera-Losada et al., 2017)
		Soil and water conservation	Practising of soil and water conservation methods	Categorical (Yes, no)	Practising of soil and water conservation methods, higher the resilience (Akinnagbe & Irohibe, 2015; Jamshidi et al., 2019)
		Slope of the land	Whether the land is flat, undulating, moderate slope or steep slope	Categorical (flat, undulating, moderate slope and steep slope)	lower the slope, higher the resilience (Asmamaw et al., 2019)
Transform-ative Capacity	Infrastructure	Availability of storage facilities	Whether households have storage facilities	Categorical (Yes, no)	Having storage facilities, higher the resilience (Williams et al., 2018)
		Access to basic public services	Distance to market	Categorical (Market distance is <1 km, 1-5 km, 5-10 km, >10 km)	Higher the distance to market, lower the resilience (Williams et al., 2018)
	Social capital	Presence of middleman	Presence of middleman when marketing their products	Categorical (Yes, no)	Presence of middleman, lower the resilience (Scott et al., 2017)
		Hired labour	No. of hired labour used in farming activities	Descrete (No. of hired labours)	Use of hired labour, lower the resilience (Fagariba et al., 2018)

than 60% of HHs in Hatton were below 50 years, which could be due to their early marriages compared to other study sites. The HHs were categorized into three education categories as no schooling, primary education (grade 1 to 5) and secondary education and above (grade 6 to advanced level was considered as secondary education and diplomas, degrees, etc., were considered as post-secondary education). The summary of the education levels of HHs in four locations is shown in Table 2.

Farming was the primary employment of all HHs in the study sample of Jhikhu Khola, and the majority in Chittagong (98%) and Welimada (96%), while the majority in Hatton (67%) were day-labourers of tea estates. In Chittagong, approximately 96% of respondents cultivated only in the summer season (*Kharif I*: May–June; pre-monsoon, and *Kharif II*: July–October (monsoon rains) and were full-time farmers under rainfed systems. Due to the unavailability of sufficient water and unfavourable climatic conditions, the respondents in Chittagong did not cultivate in the Rabi season (winter season with no or little rainfall; November-April). About 95% of the farmers in Jhikhu Khola cultivated crops during the monsoon season (June-September), post-monsoon season (October-November), and the winter season (December-February). In the two sites in Sri Lanka, nearly 98% of the farmers cultivated during both growing seasons, i.e. Yala season (March-April with First Inter-monsoon and May-September with South West Monsoon) and Maha season (October-November with Second Inter-monsoon and December-February with North East monsoon).

All interviewed households in Chittagong used hired labour in at least one of the cultivation types (home garden and upland) and at least in one season. The households in Hatton did not use hired labour for any type of cultivation in both seasons. As the cultivated extent of HHs in Hatton was smaller, they did not require hired labour and cultivation was managed using family labour. The majority of households in Welimada (92%) and Jhikhu Khola (91%) were using hired labour.

The average cultivated extent of Hatton was very low (89.8 $\pm$ 76.04 m^2) compared to Chittagong (20,084.4 $\pm$ 15,148.3 m^2), Welimada (16,530.23 $\pm$ 9,461.5 m^2) and Jhikhu Khola (3,021.07 $\pm$ 1,756 m^2). A high proportion in Chittagong (97%), Welimada (95%) and Hatton (61 %) practised mixed-cropping while in Jhikhu Khola, a higher proportion (67%) practised sole cropping with paddy as the main crop in valleys. All the respondents in Welimada, 79% in Chittagong, 30% in Jhikhu Khola and 27% in Hatton cultivated high yielding hybrid crops. About 97% of the households in Chittagong used synthetic fertilizer in their cultivations and no household in the study site opted for integrated fertilizer usage (synthetic + organic fertilizers), while 71% in Welimada used only synthetic fertilizers. Integrated fertilizer management was practised by 45% in Jhikhu Kola, 75% in Hatton and 20% in Welimada.

About 99% of Chittagong interviewees used rainfed cultivation both in home garden systems and upland cultivation. All Interviewees in Hatton cultivated both rainfed and irrigated lands and did not have lowlands to cultivate. In Jhikhu Khola, a higher proportion of interviewees cultivated their home gardens and uplands only as rainfed, while the majority of the lowlands were rainfed and irrigated. In Welimada, the majority of the home gardens were only rainfed, while lowlands and uplands were rainfed and irrigated.

The majority of households in Jhikhu Khola (98%) and Chittagong (62.5%) reared animals, while only 38% in Hatton and 24% in Welimada did animal farming. Among animal rearing households in Chittagong, 98% of the interviewees reared poultry while 8% reared cattle and 30% swine. The majority of households in the other three locations reared cattle rather than poultry. Goat farming was observed in Jhikhu Khola and Hatton. Species diversity among animal-rearing households in each location is illustrated in Figure 1. Among the farm animal-rearing households, 83% in Welimada, 38% in Hatton, 12% in Jhikhu Khola and 3% in Chittagong reared high yielding hybrid cattle/swine/poultry.

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Education level	Bangladesh Chittagong (%)	Nepal Jhikhu Khola (%)	Sri Lanka Hatton (%)	Welimada (%)
No schooling	62.5	25.7	12.8	3
Primary education	24	53.5	83.2	86
Secondary education or above	13.5	20.8	4	11

TABLE 2. Percentage of household heads in each education category of Chittagong in Bangladesh, Jhikhu Khola in Nepal, and Hatton and Welimada in Sri Lanka (Source: Survey data; N = 424).

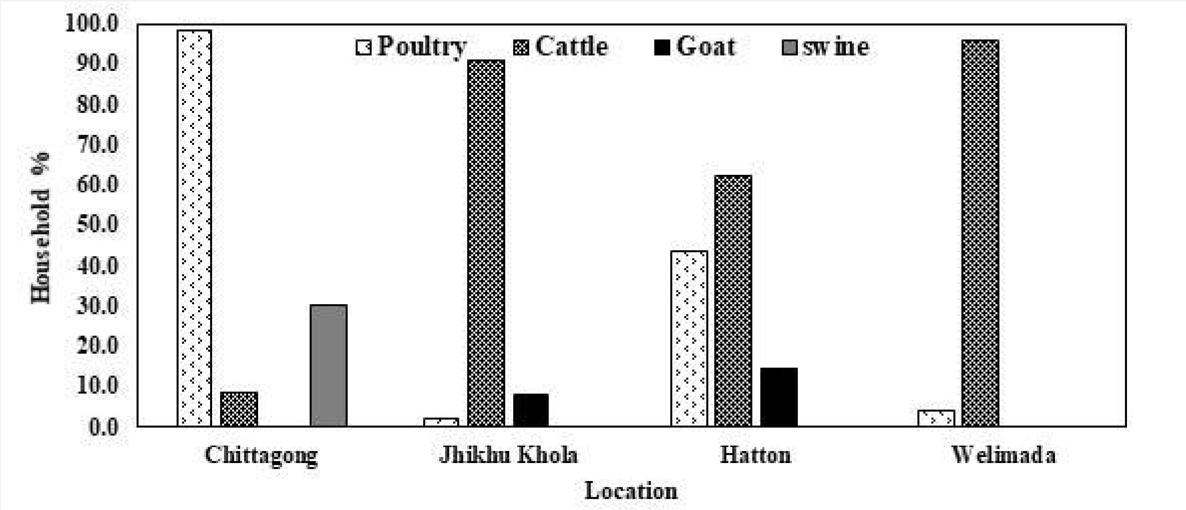

FIGURE 1. The species diversity among farm-animal rearing households of Chittagong in Bangladesh, Jhikhu Khola in Nepal, and Hatton and Welimada in Sri Lanka (Source: Survey data; N = 424).

All interviewed households in Chittagong, Hatton and Welimada, and 70% of interviewed households in Jhikhu Khola did integrated farming. In Chittagong, around 55% of the households had paddy and Other Food Crops (OFCs) such as cereals, vegetables and fruit in their uplands, while the rest of households had different combinations of paddy, OFCs, tree crops, farm animals and aquaculture (Table 3). The majority of those in Jhikhu Khola had paddy + OFCs + farm animals in their farming systems. In Hatton, 62% had OFCs integrated with tree crops (perennials) while the rest had OFCs, tree crops and farm animals in their farming systems. In Welimada, the majority (67.7%) had integrated paddy + OFCs, 22% had paddy + OFCs + animal, and 10% practised different combinations of paddy, OFCs, tree crops, farm animals, and aquaculture.

The highest average household income and expenditure was reported in Welimada and the lowest in Jhikhu Khola (Table 4).

Almost all the households in each location marketed their products, while only 2% of Jhikhu Khola households did not market their products. In Chittagong, the distance to market was 5-10 km for 67% of the households and >10 km for the rest. In Jhikhu Khola, all households had to travel <10 km distance to reach markets, and among them, 56% travel <1 km distance. In Hatton, too, the majority (36%) had to travel <1 km to reach the markets, the lowest proportion (9%) travelled 5-10 km distance, and nearly equal proportions travelled 1-5 km and >10 km to reach the markets. Interviewees in Welimada did not have markets within reach of 1-5 km distance from their households. The majority (53%) had markets access at >10 km distance, while 44 % of households had to travel 5-10 km distance to reach markets. Only 3% of households had markets close by (at <1 km distance). The majority of interviewees in Chittagong and Jhikhu Khola and all interviewees in Welimada had the intervention of a middleman in marketing their products, while the majority of the interviewees (94%) in Hatton did not experience

Type of Integrated Farming	Bangladesh Chittagong (%)	Nepal Jhikhu Khola (%)	Sri Lanka Hatton (%)	Welimada (%)
Paddy + Food crops	55.2	4.1	-	67.7
Paddy + Animal	-	2.7	-	-
Paddy + Food crops + Animal	-	86.3	-	22.2
Paddy + Animal + Aquaculture	-	5.5	-	-
Other	44.8	1.4	-	10.1
Food Crops + Tree Crops	-	-	62.4	-
Food Crops + Tree Crops + Animals	-	-	37.6	-

TABLE 3. Percentage of households who practice different integrated farming methods at Chittagong in Bangladesh, Jhikhu Khola inNepal, and Hatton and Welimada in Sri Lanka (Source: Survey data; N = 424).

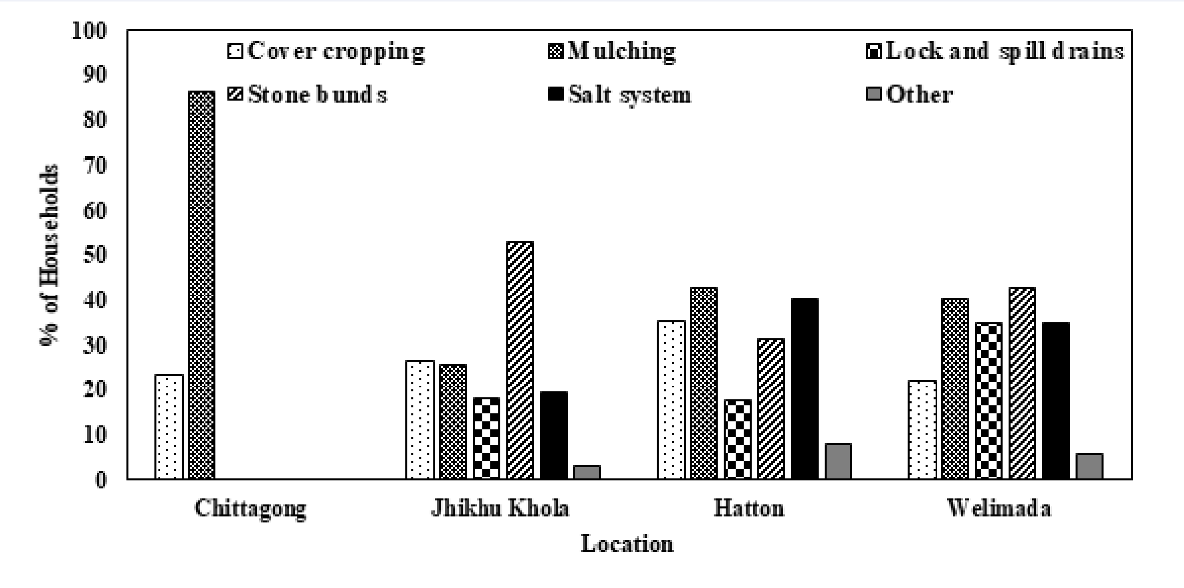

FIGURE 2. Percentage of households who practise different soil and water conservation methods in Chittagong, Bangladesh; Jhikhu Khola in Nepal; and Hatton and Welimada in Sri Lanka (Source: Survey data; N = 424)

Location		Average Income (USD / Month)	Average Expenditure (USD / Month)
Bangladesh	Chittagong	207.5 ± 134.5^{a}	151.84 ± 89.99^{b}
Nepal	Jhikhu Khola	201.7 ± 163.1^{a}	145.43 ± 86.05^{b}
Sri Lanka	Hatton	221.66 ± 105.95^{a}	171.24 ± 76.59^{b}
	Welimada	255.7 ± 199.5^{a}	241.1 ± 237.7^{a}

TABLE 4. Average monthly income and expenditure of the households of Chittagong in Bangladesh, Jhikhu Khola in Nepal, and Hatton and Welimada in Sri Lanka (Source: Survey data; N = 424). Note: Within a column, means followed by the same letters are not significantly different at p = 0.05.

the involvement of a middleman when marketing their products. All households in Chittagong and Welimada had their own storage facilities and the majority of the households in Jhikhu Khola (69%) and Hatton (92%) did not have their own storage facilities for their produce.

All interviewees in Hatton and Welimada had septic tanks at their homesteads. In Chittagong, the majority of the households were using other types of toilets such as temporary pits in their own lands and 3% had open pit-type toilets. Using outside land was recorded only in Jhikhu Khola (7%), but 91% had septic tanks.

3.2. Climate Resilience Index

Since climate resilience cannot be measured directly, to explore households' resilience to climate change and climate change-induced shocks, a climate resilience index (CRI) was developed. The CRI*i* score ranged between 0 (negligible climate resilience) and 1 (high climate resilience). Each household in this study had a CRI between 0.36 and 0.76. Table 5 shows the average climate resilience scores for each location. Among the four study sites, the average CRI was highest in Hatton, while the lowest was recorded in Chittagong.

The cut-off points for each resilience category and percentage of households in the respective resilience category are shown in Table 6.

The cut-off points of the index are relative measures and this categorization supports comparison of farming systems within and among sites. However, variation among households was observed within the four study sites.

Table 7 shows the average contribution of each parameter used in the study to the CRI, which provides the relative influence of those parameters forclimate resilience of each study site.

3.2.1. Climate resilience in Chittagong (Bangladesh)

In Chittagong, the majority of households (60.4%) were in the less resilient group and 18.8% each were in the least and moderately resilient groups, respectively. Only 2.1% of the households were in the category of highly resilient, while none of the households were categorized as very-highly resilient. Figure 4 illustrates the spatial distribution of climate resilience in Chittagong. The FSUs in all resilience levels were scattered throughout the study site across different elevations, showing that there is no relationship between elevation and the CRI.

Chittagong was the least climate-resilient site among the four study sites. The parameters that contributed most to Chittagong being the least climate resilient were: household heads with no proper education (0.83), households with only one income source (0.93), presence of unemployed members in the household (0.99), no savings (very low income:expenditure ratio) (0.86), higher income share from farming for livelihood (0.99), lack of proper housing (0.79) lack of proper sanitary facilities (0.98), use of hired labour (1.0), cultivating hybrid crops (0.79), relying only on synthetic fertilizers (0.97), cultivations are only rainfed (0.99), presence of middleman when marketing their produce (0.91), and having land with steep slopes (0.85). The factors that contributed to increasing climate resilience in Chittagong were: having a male household head (0.99) who are not dependents (0.94), having land ownership (0.67), cultivating more than three crops (0.9), having mixed-cropping systems (1.0), implementing good animal husbandry practices (0.90), having storage facilities (1.0), consuming products from own crop cultivations (0.92) and animal husbandry (0.72), having woody trees in their land (1.0), having noticed changes in climate (1.0) and changes in farming systems (1.0).

3.2.2. Climate resilience in Jhikhu Khola (Nepal)

Compared to Chittagong, climate resilience was high in Jhikhu Khola in Nepal. A higher proportion (43.7%) of the households in Jhikhu Khola were in the highly resilient category, followed by 39.8% under a moderately resilient category and 6.8% in the very-highly resilient category. About 8.7% of the households in Jhikhu Khola were the less resilient group, and 1% were least resilient to climate change. The spatial distribution of climate resilience is

Index	Bangladesh	Nepal	Sri Lanka	
	Chittagong	Jhikhu Khola	Hatton	Welimada
Climate Resilient Index (CRI)	0.48	0.59	0.67	0.6

TABLE 5. Average CRI Values of Chittagong in Bangladesh, Jhikhu Khola in Nepal, and Hatton and Welimada in Sri Lanka (Source: Survey data; N = 424).

Resilience level	Cut Off Points	% of Households in different resilience levels			
		Bangladesh	Nepal	Sri Lanka	
		Chittagong	Jhikhu Khola	Hatton	Welimada
Least Resilient	0.36 - 0.44	18.8	1	0	0
Less Resilient	0.44 - 0.52	60.4	8.7	0	6
Moderately Resilient	0.52 - 0.60	18.8	39.8	11.2	40
Highly Resilient	0.60 - 0.68	2.1	43.7	46.4	51
Very Highly Resilient	0.68 - 0.76	0	6.8	42.4	3

TABLE 6. The cut-off points for each resilience category and percentage of households in respective resilience category for each site.

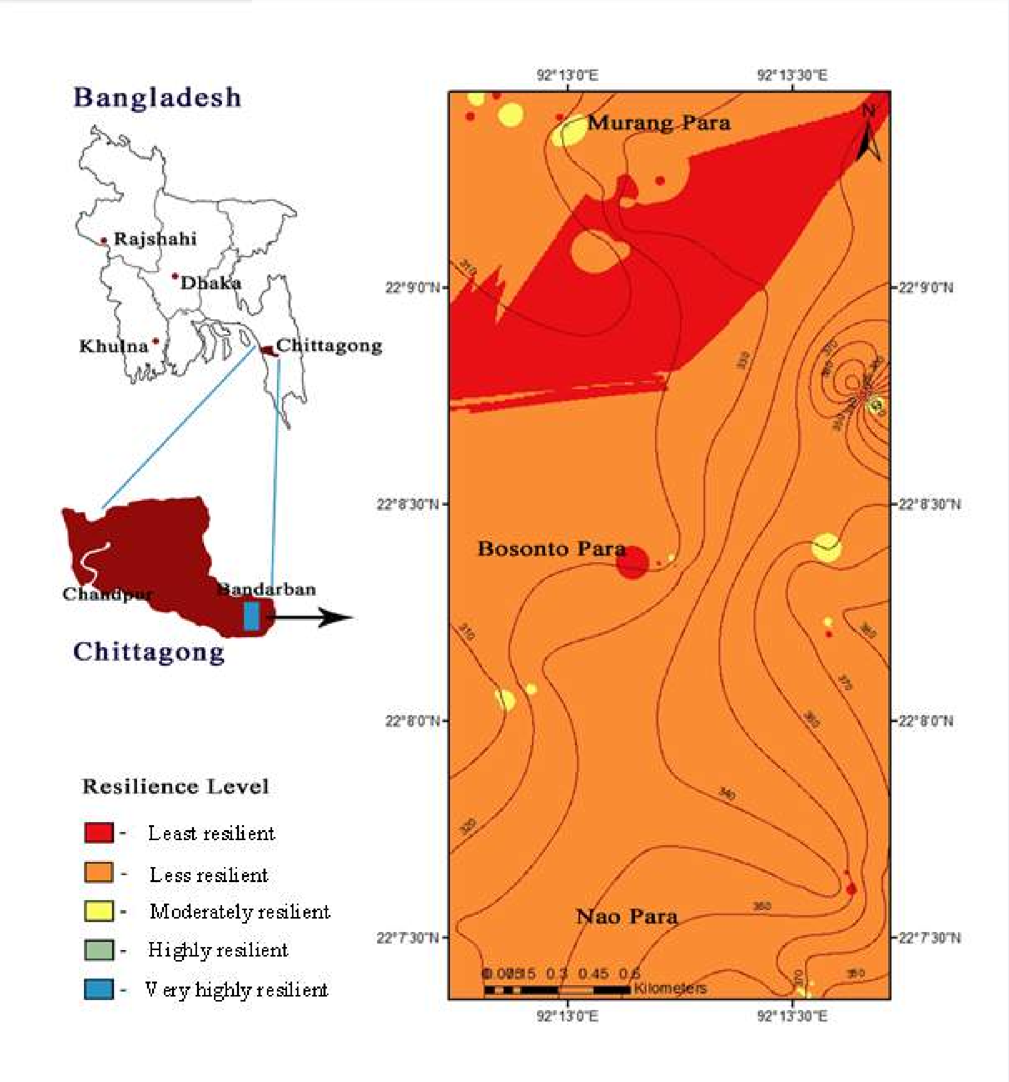

FIGURE 3. The spatial distribution of climate resilience of Chittagong in Bangladesh.

Parameter	**Expression**	**Relative Contribution of paramters to CRI**			
		Bangladesh	**Nepal**	**Sri Lanka**	
		Chittagong	**Jhikhu Khola**	**Hatton**	**Welimada**
Sex of the household head	Female headed households	0.01	0.04	0.11	0.08
Age of the household head	Presence of dependent household heads	0.06	0.13	0.14	0.17
Condition of house	Do not have proper housing	0.79	0.67	0.33	0.10
Educational level	Household heads with primary education or no schooling	0.83	0.68	0.70	0.64
Property regime	Do not have own lands	0.33	0.17	0.67	0.22
Diversified income sources	Have only one income source	0.93	0.40	0.11	0.23
Household employment	Any member of household is not employed	0.99	0.98	0.16	0.89
Income/expenditure	No savings	0.86	0.83	0.86	0.86
Share of income from farming	Share of income from farming is more than 50%	0.99	0.20	0.32	0.48
Practising of animal husbandry	Do not practice animal husbandry	0.38	0.01	0.62	0.76
Species diversity	Rearing only one animal species	0.10	0.33	0.21	0.17
Animal breed	Rearing Hybrid animals				
System of rearing	Animals are rearing extensively				
Method of feeding	Do not feed concentrate feeds				
Experience in farming	Farming experience in years (Less)	0.61	0.65	0.80	0.52
Living period in the area	Living period in years (Less)	0.66	0.66	0.53	0.32
Climate change	Have not notice the changes in climate	0.00	0.26	0.00	0.00
Changes in farming system	Have not noticed the changes in farming system	0.00	0.17	0.00	0.06
Food from own crop cultivation	Do not consume own products from crop cultivation	0.08	0.00	0.00	0.00
Food from animal husbandry	Do not consume own products from animal husbandry	0.28	0.67	0.92	0.95
Type of toilet	Do not have septic tank or sewerage system type toilets	0.98	0.07	0.00	0.00
Crop diversification	Cultivate less than three crops	0.10	0.02	0.17	0.00
Cropping System	Cultivate as sole crop	0.00	0.64	0.39	0.15
Cultivated variety	Cultivate hybrid varieties	0.79	0.30	0.27	1.00
Fertilizer management	Use inorganic fertilizer only	0.97	0.43	0.19	0.71
Water usage in farming system	Cultivations are only rainfed	0.99	0.49	0.00	0.30
Presence of naturally grown plants	Do not have naturally grown plants	0.51	0.00	0.41	0.27
Presence of woody trees	Do not have woody trees	0.00	0.02	0.00	0.18
Following soil and water conservation methods	Not following soil and water conservation methods	0.63	0.65	0.00	0.04
Slope of the land	Having lands with steep slope	0.85	0.33	0.96	0.61
Availability of storage facilities	Do not have own storage facilities	0.00	0.72	0.92	0.06
Access to basic service	Distance to market is more than 10 km	0.44	0.14	0.43	0.68
Presence of middleman	Middlemen is present	0.91	0.87	0.06	1.00
Use of hired labor	Use hired labors	1.00	0.97	0.00	0.86

TABLE 7. The relative contribution of each parameter to the CRI Values of Chittagong in Bangladesh, Jhikhu Khola in Nepal, and Hatton and Welimada in Sri Lanka (Source: Survey data; N = 424).

demonstrated in Figure 4. As FSUs in all resilient levels were scattered throughout the study site, no direct relationship could be established between the CRIi and the elevation of the location of FSUs.

The important factors that have contributed to reducing the climate resilience of FSUs in Jhikhu Khola study site in Nepal were: household heads without proper education (0.68), no members in the household employed with an additional income (0.98), no savings (0.83), absence of storage facilities (0.72) and presence of middleman when marketing their produce (0.87), use of hired labour (0.97), not consuming products from animal husbandry (0.67) and not having proper housing (0.67).

As indicated in Table 7, factors such as male household heads (0.96) who are not dependents (0.87), cultivating more than three crops (0.98), not cultivating hybrid crop varieties (0.7), consuming products from own crop cultivation (1.0), market distance less than 10 km (0.86), presence of naturally grown plants (1.0) and woody trees (0.98), having land ownership (0.83), land that is not steep (0.67), having proper sanitary facilities (0.93), not relying totally on agriculture-based income (0.80), practising farm animal husbandry (0.99), implementing good animal husbandry practices (0.67) and having noticed changes in climate (0.74) and changes in farming systems(0.83) contributed significantly to increased the climate resilience in Jhikhu Khola site.

3.2.3. Climate resilience in Hatton (Sri Lanka)

As shown in Table 6, Hatton did not have households that fall into the least or less climate-resilient groups. A higher proportion (46.4%) of the households in Hatton were in the highly climate resilient group, 42.4% were very-highly resilient and 11.2% were moderately resilient. Figure 5 illustrates the spatial distribution of the climate resilience in Hatton, which showed the highest climate resilience among the four locations. Similar to the observation made in the other sites, the elevation among the location of FSUs varied largely. Therefore the level of resilience in the FSUs could not be related to the elevation.

Being the most resilient among the study sites (Table 5), parameters such as presence of male household heads (0.89) who are not dependents (0.86), having more than one income source (0.89), presence of employed members in the household (0.84), not relying totally on agriculture-based income (0.68), cultivating more than three crops (0.83), use of local crop varieties (0.73) and organic fertilizers in their cultivations (0.81), consuming products from own crop cultivation (1.0), not using hired labors (1.0), marketing their products without a middleman (0.94), availability of irrigation facilities (1.0), presence of woody trees in their land (1.0), practicing of soil and water conservation methods (1.0), implementing good animal husbandry practices (0.79), having proper housing (0.67) and sanitary facilities (1.0) and having noticed the changes in climate (1.0) and the changes in farming system (1.0) have contributed to increase the climate-resilience of the FSUs in the Hatton study site, compared to those in Chittagong, Jhikhu Khola and Welimada. However, household heads without proper education (0.70), not having storage facilities (0.92), not consuming own products from animal husbandry (0.92), having landwith steep slopes (0.96), no savings (0.86), not having own land (0.67), and having less experience in farming (0.8) have contributed to reducing the climate resilience of the FSUs of the Hatton study site.

3.2.4. Climate resilience in Welimada (Sri Lanka)

In Welimada, 51% of the households were highly climate resilient, 40% were moderately resilient, 3% were very-highly resilient, while 6% were less resilient. There were no households from the Welimada site that belonged to the least climate resilient group. Figure 6 demonstrates the spatial distribution of the climate resilience in Welimada. The FSUs in all resilience levels were scattered throughout the study site across different elevations, showing that there is no relationship between elevation and the CRI.

As presented in Table 7 parameters such as, presence of male household heads (0.92) who are

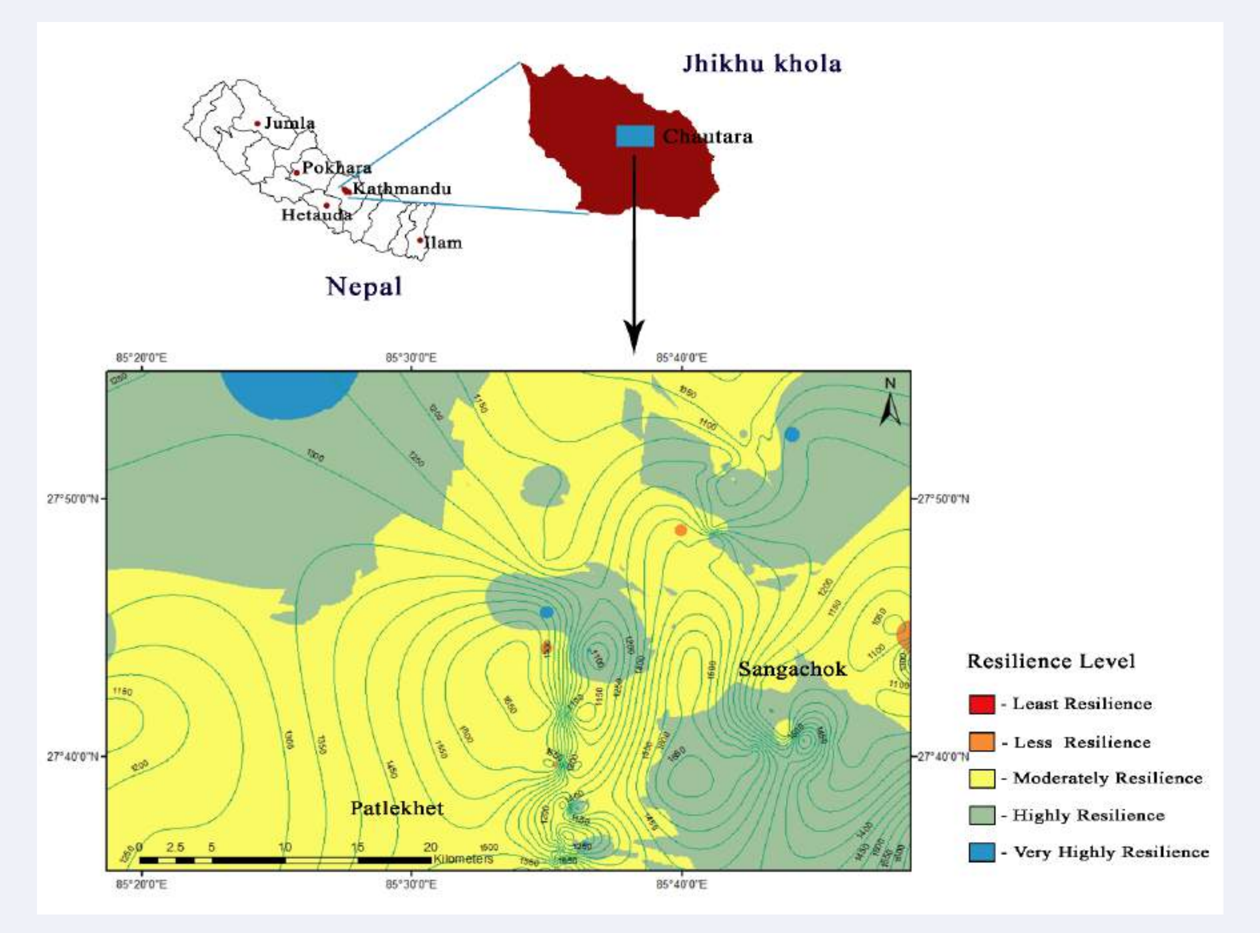

FIGURE 4. The spatial distribution of climate resilience of Jhikhu Khola in Nepal.

not dependents (0.83), cultivation of more than three crops (1.0) as mixed cropping (0.85), availability of irrigation facilities (0.70), consuming products from own crop cultivation (1.0), having storage facilities (0.94), presence of naturally grown plants (0.73) and woody trees (0.82) in their land, following soil and water conservation methods (0.96), having land ownership (0.78), proper housing (0.90) and proper sanitary facilities (1.0), having more than one income source (0.77), implementing good animal husbandry practices (0.83), having a higher lifespan in the area (0.68), and having noticed changes in climate (1.0) and changes in farming systems (0.94) have contributed to increasing climate resilience in the Welimada study site. However, unemployed members in the household resulting in no additional income (0.89), no savings (0.86), cultivation of crop hybrids (1.0), using only inorganic fertilizers (0.71), using hired labour (0.86), not practising animal husbandry (0.76) and not consuming products from own animal husbandry (0.95), distance to market is more than 10 km (0.68) and presence of middleman when marketing their products (1.0) are the factors which have contributed to reducing climate resilience in the Welimada study site in Sri Lanka.

4. DISCUSSION

Climate is the primary determinant of agriculture (Berhane, 2018) and climate change affects agriculture and food production through direct effects on production to markets and supply chain infrastructure (Gregory et al., 2005), thus increasing the climate vulnerability of a farming community. The study revealed that female-headed households are more likely to be vulnerable to climate-induced stresses and shocks compared to male-headed households, as the females face gender discrimination with respect to resources, rights, education, income and economic opportunities (Opiyo et al., 2014;

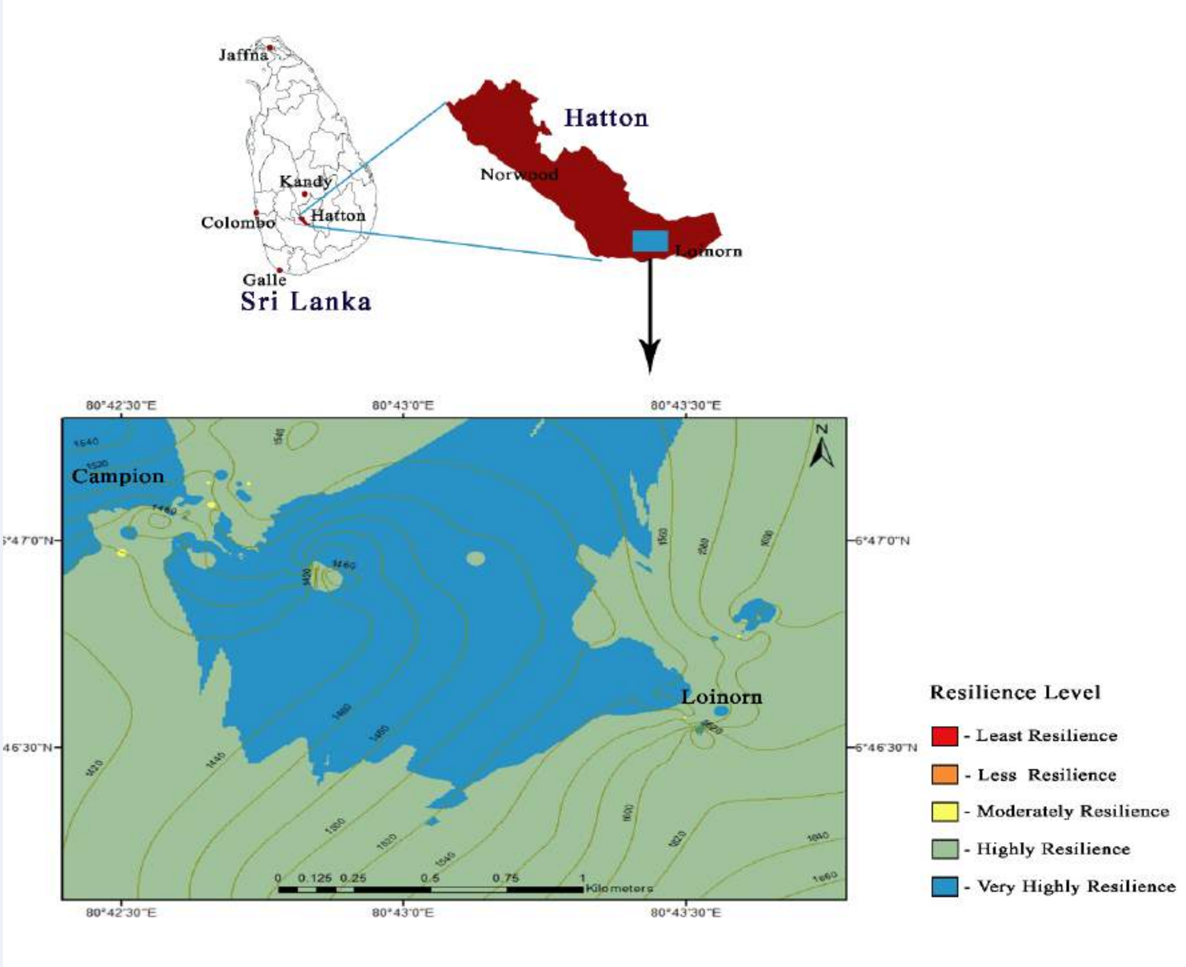

FIGURE 5. The spatial distribution of climate resilience of Hatton in Sri Lanka.

Alhassan, Kuwornu, & Osei-Asare, 2018). In this study, HH was considered the decisionmaker of the household. As the education level matters in decision making, a low level of education of HH may lead to reduced resilience. Moreover, households headed by the elderly (above 65 years of age) are more likely to be vulnerable compared to those having younger household heads. Opiyo et al. (2014) reported that elderly household heads are weak in preparing strategies to protect their families against adverse climatic stresses thus making them less climate-resilient.

In the present study, the majority of households in Chittagong, Jhikhu Khola and Welimada had only HH employed, which has led to reliance on agriculture as the main source of livelihood. In Hatton, the majority of the respondents are day labourers of tea estates and the income from the job was the main source of livelihood. In general, households with a diversity of income sources are less vulnerable and are able to quickly recover against climate change-induced shocks than those who are solely dependant on a single source of income (Akinnagbe & Irohibe, 2015; Asmamaw et al., 2019). When climate change affects income sources, financial stability of a household is challenged. Moreover, extreme climate events affect food production and availability, hence trigger food price hikes and affect the earnings of poor people (Gregory et al., 2005), making them more vulnerable.

The households selected in this study who had multiple income sources, large asset holding and strong social capital were more resilient to climate-induced shocks than the rest. Iqbal, Ahmad, and Rafique (2015) reported that households with more than one income source would have added advantages in terms of increased purchase power in a changing climatic scenario. Compared to Chit-

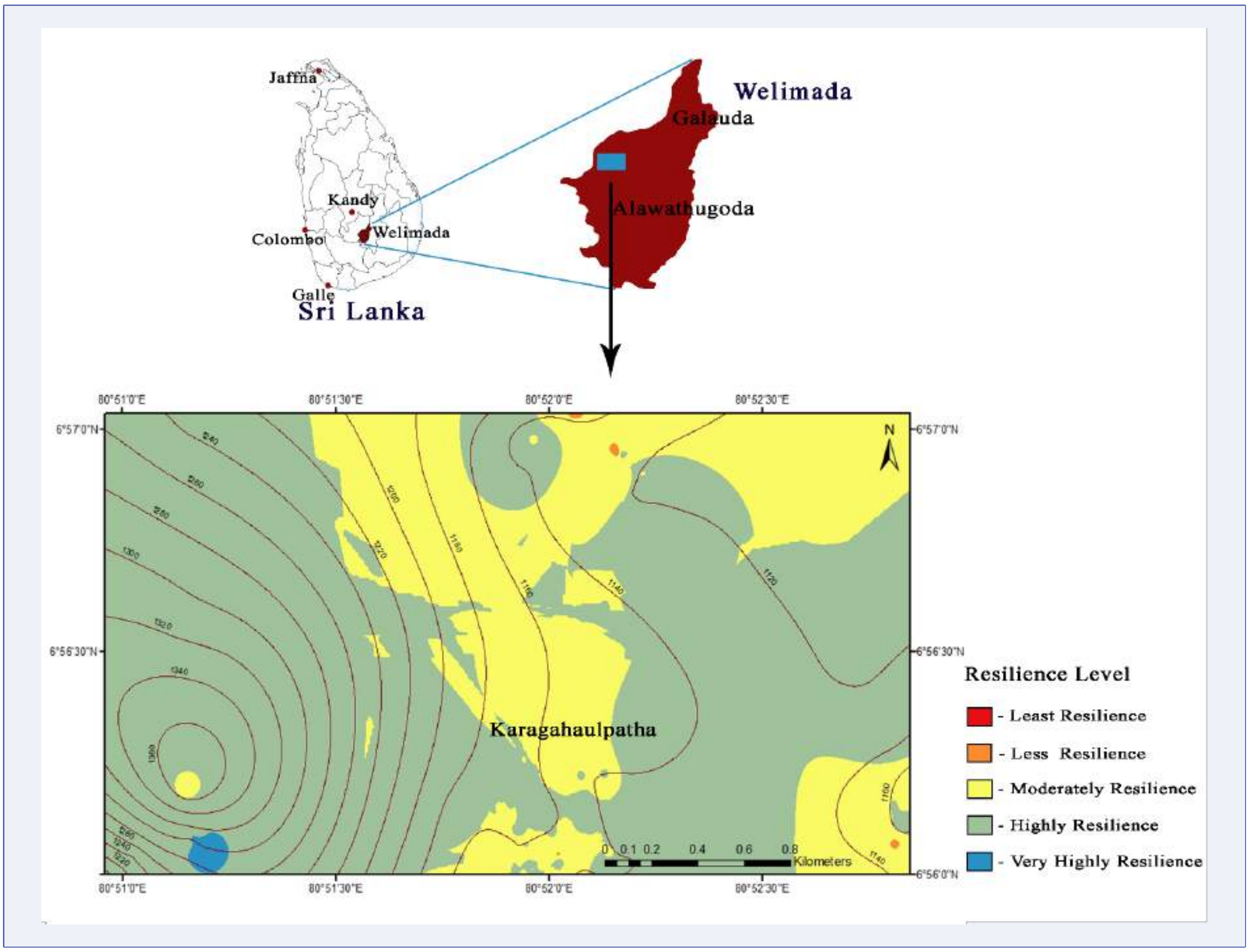

FIGURE 6. The spatial distribution of climate resilience of Welimada site in Sri Lanka.

tagong, the majority of the respondents in the other three locations had more than one income source and did not rely totally on agriculture-based income resulting in comparatively high climate resilience. If the households are able to save more, it would help in allocating more finances for food purchases and other basic needs in emergencies due to climate change. As explained by Asmamaw et al. (2019), there is a positive and direct association of diversity of income sources with resilience.

High yielding crop varieties are more sensitive to changes in climate and susceptible to climate-induced pest and disease attacks, etc. (Negi, 1994; Abewoy, 2018). Hence, cultivating high yielding hybrids have contributed to increasing the vulnerability in Chittagong and Welimada. The development of tolerance of crop hybrids to excess soil moisture, drought, and pest and disease incidences will be helpful to overcome the impacts of climate change with more adaptability, thus increasing resilience. The sensitivity of different crops to climate change will vary. The presence of different crop categories in a farming system could reduce crop failures in a changing climate (Iqbal et al., 2015) thus, increasing resilience. In all study sites, the majority of the respondents cultivated more than three crops, thus contributing to increased climate resilience.

The practice of farm animal husbandry and the presence of diversified food and income sources (FAO, 2020; Sansoucy, 1995) have been identified to increase climate resilience. In Chittagong and Jhikhu Khola, the majority of households practised animal husbandry, thus increasing their resilience to climate-induced shocks. However, the number and diversity of animals would critically impact their economic returns (Rojas-Downing et al., 2017). Compared to high-productivity breeds, indigenous breeds are more resistant to locally prevailing diseases and ensure higher survival rates, minimizing expenditures for veterinary services, better tolerate the weather extremes and periods of feed scarcity, and can survive on low-quality forage (Ahmed et al., 2013; Rahim et al., 2013). As stated by Hidosa and Guyo (2017), climate change is expected to affect livestock feed in terms of quality and quantity. Hot and dry seasons have induced the greatest reduction in biomass yield for different types of grass-growing in low land environments resulting in low feed availability. In the changing climate scenario, nutritional stress act as the most important indirect stress affecting livestock, leading to decreased performance (Chaidanya et al., 2015). Hence, in the changing climatic scenario, the livestock needs to be protected against the adverse effects of environmental stresses to maintain production and performance by providing optimum nutrition, proper management practices and health care. Grazing animals in arid and semiarid regions are generally subjected to periods of under-nutrition during extreme hot environments due to non-availability of feed and poor pasture conditions caused by lower availability of nutrients, which in turn results in low productivity. Feeding concentrates (Hidosa & Guyo, 2017) and intensive rearing of livestock (Rust, 2018) are increasing resilience to climate change.

Consumption of own products from cultivation and animal rearing could reduce the expenditure on food purchase of a household, thus lowering the food insecurity (FAO, 2015, 2020). The results of the present study clearly indicated that consumption of products from the own crop cultivations has contributed to increasing climate resilience in all study sites. With the availability of proper storage facilities, farming households would store the farm products for extended usage, as well as to obtain better prices for their farm products (Jobbins & Henley, 2015), facilitating the increase in food availability and income thus, leading to lower vulnerability. In Chittagong and Welimada, this was one of the contributing factors to enhance climate resilience. It is important to note that majority of the households in Jhikhu Khola and Hatton did not have storage facilities, despite having higher resilience. Hence such interventions would help farming households increase their level of climate resilience.

The misuse of synthetic fertilizers has led to several issues, such as leaching losses, resulting in lower land productivity. Increased application of organic manures/fertilizers would enhance soil organic matter (and thus soil organic carbon) content and improve soil structure (Müller, 2009), increasing soil biological activity, maintaining long-term soil fertility, reducing nutrient losses from synthetic fertilizers, and promoting a healthy soil environment, while minimizing environmental pollution. The combined use of synthetic and organic fertilizers would thus enhance the fertilizer and nutrient use efficiency thereby enhancing crop/land productivity and reducing climate vulnerability. In Chittagong and Welimada, the majority of the households used synthetic fertilizers, with minimum use of organic manure/fertilizers, thus reducing climate resilience.

Farming systems located on steep slopes with infertile land and minimum effort made for soil and water conservation are less resilient to shock impacts (Asmamaw et al., 2019). Furthermore, the adoption of soil and water conservation measures would lead to quick recovery from the adverse impacts of erosion (Akinnagbe & Irohibe, 2015; Jamshidi et al., 2019). In Chittagong and Hatton, steep land was one of the most contributing parameters to increase climate vulnerability. However, the majority of households in both these sites practised soil and water conservation measures, thus increasing their level of climate resilience. Moreover, households with land ownership are more likely to invest in land, soil and water conservation, and thus, are more likely to bounce back quickly against climate-shock impacts (Ali & Erenstein, 2017; Asmamaw et al., 2019; Roth, 2013).

Proper sanitary facilities is one of the health concerns and lack of improved sanitation is known to increase the risk of transmission of diseases under climate shocks (Schnitter et al., 2019). With a projected increase in extreme rainfall events (Punyawardena & Premalal, 2013) and increasing climatic hazards (e.g. floods), the study sites could be experience increased transmission of human diseases owing to high vulnerability. The presence of naturally grown plants and woody vegetation in agricultural lands facilitate temperature stability and reduce the impact of extreme heat and the potential of ammonia and nitrous oxide volatilization, and thus, greenhouse gas (GHG) emissions. Furthermore, such plant cover will help in nutrient recycling from agricultural land, improve land productivity and water retention and be associated with higher biodiversity, which increases climate resilience (Cleland, 2011; Mosquera-Losada et al., 2017).

The proportion of vulnerable people increases with elevation in mountain ecosystems (Huddleston et al., 2003) . Further, species in high altitude areas are found to be more vulnerable to climate change (Tsering et al., 2010). In the present study, irrespective of the elevation, highly and less resilient households could be found (Figures 3, 4 and 5). Further, it was found that there is no correlation between elevation and CRI*i*. This scattered distribution clearly demonstrates that the resilience to climate change does not depend on the elevation. The results of the present study also revealed that there are diverse levels of integrations of crops, livestock, agroforestry, etc., in the farming systems of mountain ecosystems in all study sites. Strategies such as crop selection according to agroecology, crop diversification, mixed cropping, adopting soil and water conservation methods, having diverse income sources, consuming products from own crop cultivation and animal husbandry, etc., are practised by many households irrespective of the altitude, which would have contributed to increasing the climate resilience of households.

From the results of the socioeconomic survey (APN, 2021), factors such as the practise of both crop cultivation and animal husbandry, cultivation of diverse crops through mixed cropping, consumption of foods from own crop cultivation and animal husbandry, the economic stability of the household with more than one income source, presence of employed members in the households in addition to the HH, etc.), presence of naturally-grown plants and woody trees in the land, adopting integrated farming and soil and water conservation methods, having a house in good condition, knowledge of the HH on the changes in climate could be identified as characteristics of a climate-resilient farming system. However, the contribution of each factor varies from site to site as well as among farming systems. Identification of good management practices of the mountain farming systems with high climate resilience and implementing those practices in vulnerable ecosystems would lead to increase climate-resiliency and wellbeing of farming communities in steep terrain in mountain ecosystems at national and regional levels.

5. CONCLUSION

The study revealed that the farming systems in mountain areas in Chittagong (Bangladesh), Jhikhu Khola (Nepal), and Hatton and Welimada (Sri Lanka) differ in their size (extent), composition, resource utilization, and sustainable management practices adopted by the farmers.

Among four study sites, the average value for climate resilience was highest in Hatton with a CRI of 0.67 and the lowest in Chittagong with a CRI of 0.48. The Hatton study site had the highest proportion of households with very highly resilient farming systems in steep terrains, followed by Welimada, Jhikhu Khola and Chittagong. None of the households in the study sample in Chittagong could be categorized as having very high resilient farming systems. Different demographic, socioeconomic and environmental parameters under ADC, ABC and TC have contributed at different scales to the level of climate resilience of farming systems in steep terrains in hilly areas in the four study sites. Identification of factors that would contribute to increasing the resilience of households and hence the climate resilience in each site is necessary to address the site-specific issues and improving the already existing good practices to build climate resilience in farming systems in steep terrain.

6. POLICY IMPLICATIONS

The changing climate with extreme and unpredictable weather events have significant impacts on regional, national, and local development efforts and have added challenges to the communities of developing countries in their development interventions since the impact of climate change goes beyond specific sectors, geographic areas, communities and ecosystems.

Farming systems in developing countries are highly vulnerable to climate change impacts (Engle et al., 2013; Mendelsohn, 2008; Marambe et al., 2015). To promote climate-resilient development and to reduce these potential climate change impacts, decision-makers and development practitioners need to understand the climate vulnerabilities of the people, sectors, and places that they care about (USAID, 2016). Therefore, there is a growing need for approaches and concepts to assess climate vulnerability, adaptation and resilience and to monitor the progress in achieving resilience on national, sub-national and regional levels (Welle et al., 2014).

Assessment of climate resilience facilitates the understanding of environmental processes and would make governments and policymakers better equipped to develop sustainable solutions that could combat the effects of climate change. It also guides in establishing the idea of vulnerable and stable socio-ecological systems.

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Case study

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Capacity building at community forestry level for synergistic implementation of NDCs' adaptation and mitigation commitments

Binaya Raj Shivakoti [a] *, **Federico Lopez-Casero** [a], **Tek Maraseni** [b], **Krishna Pokharel** [c]

[a] Institute for Global Environmental Strategies (IGES), Kanagawa, Hayama, Japan
[b] Centre for Sustainable Agricultural Systems, University of Southern Queensland, Queensland, Australia
[c] Koteshwor, Kathmandu, Nepal
* *Corresponding author. Email: shivakoti@iges.or.jp.*

ABSTRACT

Conservation, restoration and management of forest resources are critical for addressing climate change. Nationally Determined Contributions (NDCs) are a vehicle for targeted climate actions, including those related to forest management, by countries towards contributing global efforts agreed under the Paris Agreement. Operationalizing climate action stipulated in NDCs requires adequate preparedness and capacity, especially at the local level. This paper suggests a comprehensive framework of capacity building targeting at the community forestry level based on the findings of capacity needs assessments carried out in Nepal. The framework outlines a method to develop capacity among forest communities so they can carry out integrated assessments of the outcomes related to sustainable forest management, mitigation, adaptation and the quality of governance. Further, it outlines the capacity needed for integrated planning and implementation to consolidate the assessment process and make progress in an adaptive manner. By filling the capacity gaps at the community forestry level in a comprehensive manner, countries can narrow the existing divide between local-level climate actions and upper-level (national and international level) policy priorities, which is the major barrier for translating climate commitments into action.

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KEYWORDS

Adaptation, Capacity building, Community forestry, NDCs, REDD+, Sustainable forest management

HIGHLIGHTS

- There is a communication gap between local and national/international levels, which hampers the effective implementation of prioritized forest-related climate actions in NDCs.
- Capacity building at the community forestry level is critical for connecting priorities set out in the NDCs with effective actions on the ground by facilitating an exchange of information and support (technical, financial), and recognition of local contributions in a transparent manner.
- Given the shortcomings of stand-alone capacity building initiatives, we recommend a comprehensive approach to capacity building under a framework of sustainable forest management for synergistic outcomes as well as to safeguard the interests and rights of the forest communities.
- Ultimately, each forest community should be able to plan, decide and lead climate actions that streamline NDCs priorities while contributing to their resilience building. A comprehensive approach, therefore, is critical for long-term capacity building at the local level.

1. INTRODUCTION

Climate change affects forests significantly and forests influence climate change at different scales and in complex ways. Improved management and better governance of forest resources are critical for achieving global warming targets (1.5°C or 2°C) as well as to accelerate the global adaptation goal of the Paris Agreement (UNFCCC, 2015). The forestry sector is among the few sectors promising dividends for mitigation and adaptation simultaneously. The ability of forest ecosystems to sequester carbon and to provide multiple ecosystem services is a simple yet cost-effective nature-based solution for large-scale climate action (IPCC, 2019; Austin et al., 2020; Girardin et al., 2021).

Forests are simultaneously a source (i.e. problem) and a sink (i.e. solution) for greenhouse gas (GHG) emissions as global forests contain vast carbon stock (i.e. including all carbon pools) of an estimated 662 gigatonnes CO_2 equivalent ($GtCO_2e$) (163 tonnes CO_2e per ha) in soil organic matter, living biomass, and dead wood and litter (FAO, 2020a). With current 15% of GHG emissions coming from forests, potential release of GHG from forest stock can pose a serious barrier for realizing the Paris Agreement if we consider the remaining cumulative budget of less than 600 $GtCO_2e$ (1.5°C by 2100 scenario from 2018) or the rate of the total annual global emissions (53.5 $GtCO_2e$ in 2017) (UNEP, 2018; FCPF, 2020). Land-based mitigation and land-use change is required for limiting warming to 1.5°C, or well below 2°C, by adopting different combinations of reforestation, afforestation, reduced deforestation and bioenergy (IPCC, 2019).

Forests are susceptible to climate change-induced risks such as forest fires, loss of productivity due to inadequate rainfall and excess heat, erosion/damage of the forested area from climate-induced hazards (landslides, floods, etc.). Climate change could adversely affect different dimensions of forests, including occurrences, distribution and diversity of tree species, harvest levels, and quality/quantity of ecosystem services (IPCC, 2019).

Forest conservation, restoration and management, therefore, are not only useful for mitigation, but are also equally crucial for adaptation. Forests, as a socio-ecological system (SES), offer a range of ecosystem services (provisioning, regulating, habitat support and cultural services). Interventions such as watershed conservation, preserving and restoring natural forest ecosystems, agroforestry, fire management, soil management, disaster risk management or ecosystem-based adaptation options have the potential to make positive contributions to sustainable development and enhancement of ecosystem functions and services (IPCC, 2019).

1.1. Scope of forest resources in the Paris Agreement and NDCs

Although major discussions and responses on climate change are skewed towards the mitigation potential of forests, the essence of Article 5.2 of the Paris Agreement is that climate change adaptation and other ecological functions of forests should proceed in an integrated manner with mitigation goals (UNFCCC, 2015). Climate change actions targeting forest resources, such as Reducing Emissions from Deforestation and Forest Degradation, and the Role of Conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks in Developing Countries (REDD+), cannot be stand-alone initiatives but should contribute and complement mitigation, conservation, livelihood support, and building resilience while minimizing risks and vulnerability. Major declarations such as the Paris Agreement, New York Declaration on Forests (NYDF), Global Forest Goals (GFGs) and Targets under the UN Strategic Plan for Forests 2030, Sustainable Development Goals (SDGs), and Aichi Biodiversity Targets have well-acknowledged this viewpoint (CBD, 2010; UN, 2015; UNFCCC, 2015; UN, 2017; IUCN & ForestAction, 2020; UN, 2014).

Article 5.2 of the Paris Agreement stipulates the importance of forest-related climate action. The article asks Parties to take action to conserve and enhance, as appropriate, sinks and reservoirs of GHG such as through REDD+. Further, the PA also gives a clear signal by stressing joint mitigation and adaptation approaches for the integral and sustainable management of forests.

Nationally Determined Contributions (NDCs) is another important feature of the Paris Agreement. Countries are to undertake and communicate ambitious NDCs as the global response to climate change for achieving the purpose of the agreement. NDCs adopt a bottom-up process that allows countries to submit their commitments. It is a pragmatic solution for setting realistic ambitions and ensuring effective implementation, as countries are free to decide on the content, process and timeline of intended climate action that they will take. NDCs will guide climate action and thus constitute the main vehicle for implementing, tracking and communicating progress made by each country.

The commitments expressed in many NDCs by individual countries have prominently featured forest or forest ecosystems (IUCN & ForestAction, 2020). The submitted NDCs recognize mitigation and adaptation contributions of the forest sector mostly emphasizing coordinated responses. In 165 NDCs examined, forest sector-related targets on mitigation and adaptation were submitted by 156 and 93 countries, respectively (IUCN & ForestAction, 2020). For instance, Indonesia's NDCs view mitigation and adaptation as an integrated concept, such as by reducing deforestation and forest degradation, ecosystem conservation/restoration or integrated watershed management, for achieving food, water, energy security and building resilience (GoI, 2016). Nepal's NDCs emphasize developing "mitigation-friendly forest management systems" and enhancing carbon sequestration through sustainable management of forests, programmes reducing emissions from forest areas, as well as adaptation-friendly community-based forest and climate-resilient watershed management (GoN/MoPE, 2016). The NDCs highlight building climate-resilient watersheds, making community-based forests climate adaptation-friendly, and designing and implementing community adaptation plans of action (CAPAs) based on forest and non-forest benefits.

1.2. Addressing capacity gaps for translating NDCs' commitments into actions on the ground

Despite significant improvements in policy, such as establishing mechanisms for REDD+, concrete measures to integrate climate action on the ground are yet to gain traction in the absence of meaningful participation of the concerned stakeholders such as community forestry (Cadman, Maraseni, Ma, & Lopez-Casero, 2017). Participation does not imply inviting stakeholders or filling quorum for consultations (Bastakoti & Davidsen, 2016; Cadman et al., 2017). Rather, it interweaves deeper into capacity barriers at the community level such as fully understanding the roles, responsibilities, costs and benefits involved in participation, and the ability to make informed decisions to safeguard core interest and resource sustainability (Maraseni et al., 2020). Inadequate readiness at the community level hampers the whole prospect of implementing NDCs through sustainable forest management.

The existing gap between policy and action has resulted in resources being concentrated in the upper echelons of the policy community and largely unavailable at the local level, where capacity building is needed the most (Cadman et al., 2017). For instance, gaps between international requirements for monitoring climate actions (such as MRV of REDD+) and the existing forest monitoring systems (such as the community level) can seriously hamper the implementation of planned climate action at the community level (Dhungana, Poudel, & Bhandari, 2018). Governments need to pay adequate attention by allocating proper resources to fill capacity gaps and thus, ensure meaningful participation at the local level, such as Community Forest User Groups (CFUGs), to implement NDCs and mainstream their efforts into the broader national and international processes. For that, it is crucial to fully understand the key capacity gaps and enable CFUGs to make informed decisions.

This paper proposes a comprehensive framework for capacity building in community forestry, such as CFUGs, targeting the effective implementation of NDC's adaptation and mitigation commitments. It builds largely on the observations and findings from a capacity building needs assessment (CBNA) at multi-levels conducted in five provinces of Nepal in 2019 and 2020. We expect that the recommendations will be useful for designing capacity building activities at the community forestry level to implement relevant NDC commitments not only in Nepal but also other counties.

2. METHODOLOGY

We adopted action research – in this case, capacity building of communities while identifying capacity needs – in four out of the seven provinces in Nepal. The methodological approach is shown in the Figure 1.

We conducted a series of multi-stakeholder CBNA workshops (at least one per province) consisting of lectures, focussed group discussions, trial assessment of quality of governance, group exercises and exposure visits to select community forestry sites (Lopez-Casero, Shivakoti, Maraseni, Pokharel, & APN, 2021). Each workshop had at least 25 participants. The stakeholders were made up of a diverse set of actors from all levels of government (federal, provincial, district and community) representing the environment, climate change, forestry, agriculture and local development, as well as from national and international organizations dealing in forest management, climate change, CFUGs, the Federation of Community Forestry Users Nepal (FECOFUN), etc. Lectures in each CBNA workshop covered familiarization of NDCs, measures for the integration of climate change action into the CFUGs, and monitoring and assessment of the performance of CFUGs. The lectures were delivered by national and international experts, including government officials. The focus group discussions were conducted with government officials (at district and provincial levels) and the community level

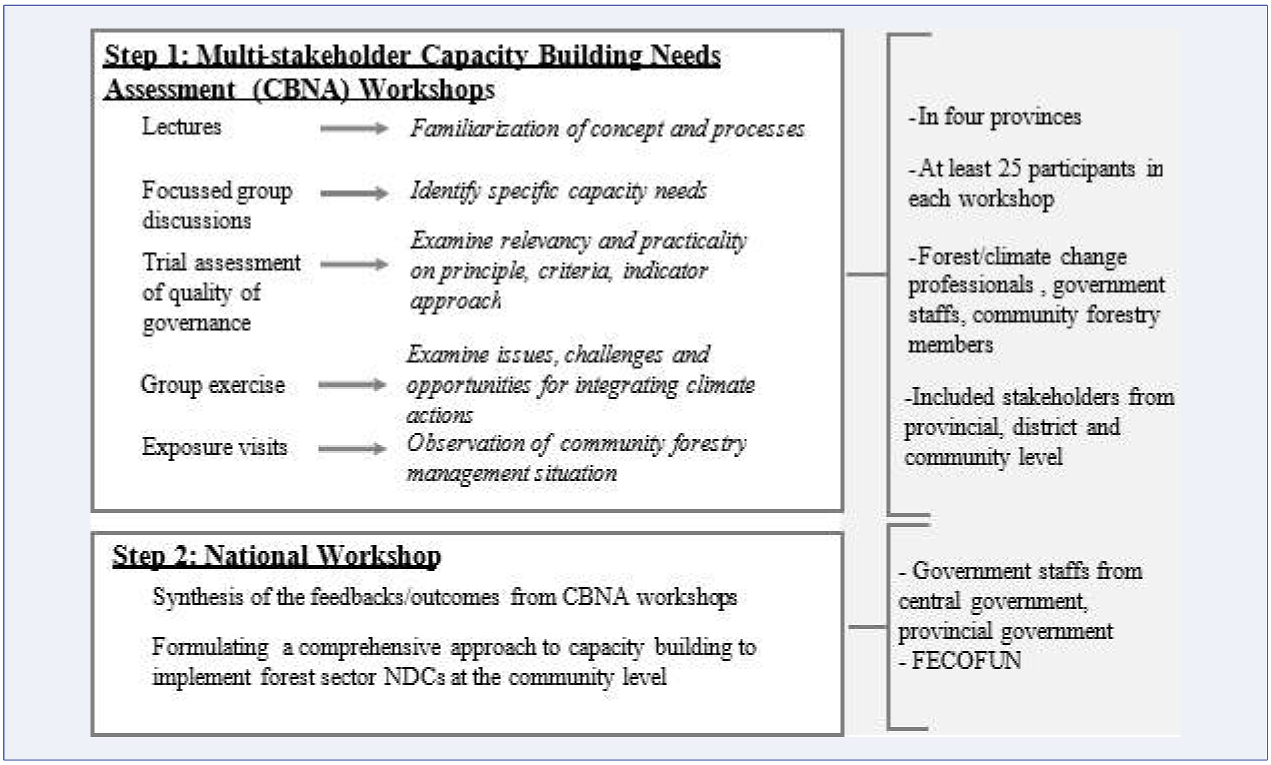

FIGURE 1. Methodological framework to identify capacity needs.

(members of CFUGs, FECOFUN) to identify capacity building needs. After the focus group discussions, trial assessment of the quality of governance (Lopez-Casero, Cadman, & Maraseni, 2016) was conducted to examine the relevancy and practicality of applying the principle, criteria and indicator framework to assess the governance, including indicators related to climate action. Further, group exercises were employed to identify challenges, needs and opportunities, such as needed resources, tools and equipment, hands-on exposure and institutional coordination required for implementing NDC commitments at the CFUG level. Exposure visits helped to further clarify the issues and challenges of forest management identified during the discussion sessions. Towards the end of the CBNA, key lessons and outcomes were shared with all participants that included identification of common concerns and expectations with regards to the modality of forest management and monitoring activities, gaps in technical and management capacity such as for monitoring carbon, how to adapt to climate change impacts and emerging concerns such as forest fires, drought, conflict with wildlife (such as monkeys), concerns on the impact of climate action such as REDD+ on the use of forest resources, social issues (migration of youth force), mainstreaming local action into national and international processes, etc. We examined the key outcomes of all CBNA workshops at the national workshop to identify a comprehensive approach to capacity building, which is also the main highlight of this paper.

3. RESULTS AND DISCUSSION

3.1. Capacity Building Needs Assessment (CBNA) at community forestry level

Community-based forest management (CBFM) is a participatory approach to managing forests under the autonomy vested to forest users (i.e. stewards) as opposed to centralized control of forest management by the government. It includes formalized customary and indigenous processes as well as government-led initiatives covering social, economic and conservation dimensions in a range of activities (FAO, 2016). Communities can play a significant role in sustainable forest management when they are empowered to participate in decision-making and equitable benefit sharing (RECOFTC, 2013). In the past four decades, CBFM regimes encompassed an estimated 732 million hectares, which is about 28% of the forests in the 62 countries or 65% of the world's forests cover (FAO, 2016). Effectiveness of CBFM is evident by its increasing coverage throughout the Asia-Pacific region such as Nepal, Viet Nam, Myanmar, China, the Philippines and many other countries (Feurer, Gritten, & Than, 2018; RECOFTC, 2013).

Nepal is considered a pioneer for successfully implementing CBFM (MOFE, 2019). Local communities under different CBFM regimes (e.g., community, collaborative or leasehold forestry) plan and manage over one-third of the forest area (MOFE, 2018). The Forest Act provides clarity on the tenure rights of the community forestry regime. As a result, CBFM has been quite successful in its core objectives for resource conservation and maintaining a supply of fodder, timber and fuelwood along with the flow of environmental and cultural services (Aryal, Laudari, & Ojha, 2020). However, as identified in the workshops, the reliance of community forestry on traditional or indigenous management practices has been unable to tap the full potential of forests to meet current needs, including climate change actions. This means that it can be challenging to ensure the full involvement of CFUGs in market-based mechanisms, such as REDD+, due to the lack of capacity in understanding the technicalities of opportunities and risks from climate change or concerns over safeguarding existing rights of CFUGs (Dhungana et al., 2018).

The integration of climate change into CFUGs governance regime is indispensable to address risks, tap into opportunities and build resilience. Forest management needs a more active and outcome-oriented approach to address livelihood expectations, contribute climate change solutions and ensure sustainability.

One basic question at the CUFGs level in Nepal is the state of preparedness to undertake reforms for contributing to NDCs commitments. The CBNA found a significant gap in understanding about the nature of involvement and incentives for integrating climate change action into the community forestry regime (Figure 2).

First, there was a need for communicating the NDCs commitments and relevant government policy and actions to CFUGs at regular intervals. CFUGs are unable to assess risks and opportunities resulting from major policy developments at the national and international levels as such information rarely reaches them. It is often hard for them to assess their role and responsibilities or incentives (benefits, support, recognition of efforts) to implement NDCs.

The second gap is on the process and scope of implementation. Targeted programmes on climate change, such as REDD+, tend to stress the carbon benefits more than other issues such as social and environmental safeguards, adaptation co-benefits and other livelihood concerns, which in principle are fully integrated into REDD+ design.

The third gap relates to monitoring and assessment. Programmes related to REDD+ involve a rigorous process of monitoring, reporting and verification (MRV) of sinks and emissions, which require extra resources and effort by communities to secure performance-based payment. In addition to carbon benefits, communities need to monitor and assess climate change impacts on forests, adaptation outcomes, the quality of governance and other non-carbon indicators related to sustainable forest management. Without adequate capacity and incentives, these requirements would simply add layers of burden to the existing forest management tasks.

The fourth gap is in the planning and implementation of climate action. This requires building technical, financial, infrastructure, human resources and institutional capacities to administer climate action transparently. Communities need to upgrade their capacity to facilitate coordination, communication and negotiation with external parties (both private and public sources offering support in the form of finance, technology, or skills). CBNA workshops identify that incorporating climate change components (mitigation and

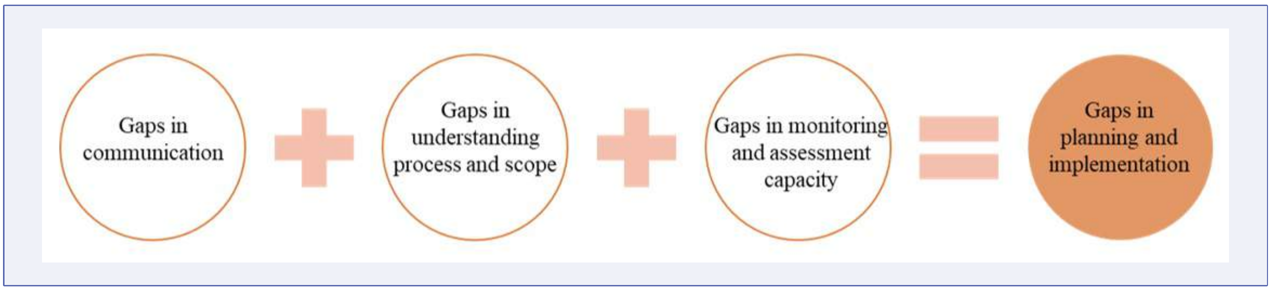

FIGURE 2. Four major capacity gaps at the community forestry user group (CUFG) for implementation of NDCs commitments targeting the forest sector.

adaptation) into forest management needs careful consideration of issues on equitable benefit sharing and additional incentives for motivating CFUGs participation.

In addition to the capacities mentioned above, the participants in CBNA workshops also identified additional issues faced by CFUGs such as rising socio-economic expectations under modern lifestyles, migration, market forces (timber and non-timber products) and land-use dynamics. These non-climatic issues reflect the concern that the design and implementation of climate change-related actions need a synergistic approach to ensure the overall sustainability of SES.

3.1.1. Comprehensive framework for capacity building at the community forestry level

In order to address the identified capacity gaps, a much broader objective for ensuring sustainable forest management (SFM) as well as addressing climate change concerns is needed. SFM is a dynamic concept that aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations (FAO, 2020b). SFM involves the application of the best available practices based on current scientific and traditional knowledge, including effective and accountable governance, that allows multiple objectives and needs to be met without degrading the forest resource and while safeguarding the rights of forest-dependent peoples (ITTO, 2015).

SFM could be the overarching concept for community forestry to follow for the effective implementation of NDCs commitments while achieving a resilient SES. Elements of SFM are comprehensive and cover state (resources, biodiversity, health and vitality), functions (production, protection and socio-economic) and enabling conditions for management (legal, policy and institutional framework) (FAO, 2020b). The broad scope of SFM signifies that it must be flexible and constantly adaptive to stay relevant and useful according to stakeholders needs, values, resources, institutions and technologies (ITTO, 2015). Because of the dynamic, multidimensional, multipurpose and multiuse framing of SFM, major assessment reports (i.e. IPCC, IPBES) or agreements/decisions (Paris Agreement, SDG15, the NYDF, GFG, Aichi Targets, etc.) frequently stress the need for its adoption and application. SFM can reduce the extent of forest conversion to non-forest uses (e.g. cropland or settlements) by providing long-term livelihoods for communities, while ensuring timber, fibre, biomass, non-timber resources and other ecosystem functions and services, lowering GHG emissions and contributing to adaptation (IPCC, 2019). SFM is one of the key pillars of REDD+ action that can help integrate and optimise carbon and non-carbon benefits. For instance, SFM allows transferring carbon to wood products, which addresses the issue of mitigation from biomass for energy (where burning releases CO_2 back into the atmosphere) and sink saturation in mature forest stands (IPCC, 2019).

Given this background and identified capacity gaps, we propose a comprehensive framework for capacity building that would enable achievement of NDCs commitment through SFM, as shown in Figure 3.

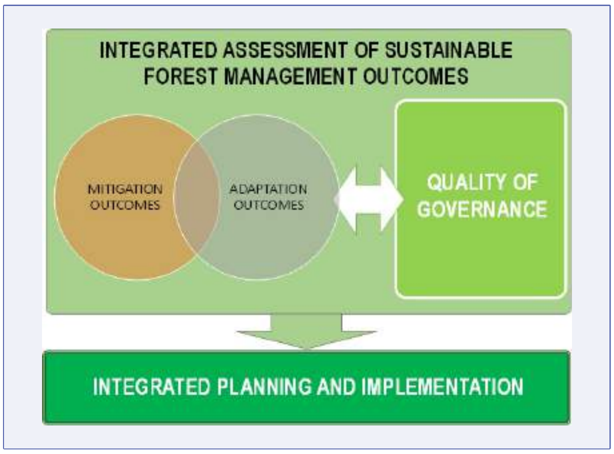

FIGURE 3. A framework for capacity building at the community forestry level for implementation of NDCs commitments through sustainable forest management.

The proposed framework consists of two parts: assessment of SFM outcomes and integrated planning and implementation. Assessment mainly covers outcomes resulting from SFM incorporating mitigation, adaptation and quality of governance. Here, the assessment of the quality of governance helps to cement the integrity of actions by ensuring transparency, participation and institutional coordination. The integrated planning and implementation (IP&I) part addresses the capacity gaps by putting in place appropriate arrangements to implement climate and non-climate action in an adaptive manner. IP&I consolidates overlapping indicators for an integrated assessment, and it can help to determine the level of coordination. IP&I can also identify resources and capacity (both available and what's needed) from external sources, and encourage adaptive planning and implementation based on the evaluation of key performance indicators.

3.2. Capacity building for the integrated assessment of SFM outcomes

Assessment is critical for examining progress on NDCs implementation, identifying challenges, and for prioritizing actions. It can be the basis to enhance ambitions or to justify requests for external support. Communities can use scientifically verifiable data generated from the assessment to identify effective forest management options and report contributions to government including requests for support or result-based payments (such as REDD+). During CBNA, the involvement of communities in the assessment was found as a critical capacity gap towards improving decision-making, both internally and when dealing with outsiders.

3.2.1. Assessment of SFM outcomes

The assessment of SFM is broad and also incorporates mitigation, adaptation and quality of governance. SFM could be a basis and starting point for designing community-level monitoring and assessment of outcomes. The assessment of SFM is generally achieved using a hierarchical approach of principle, criteria and indicators (PC&I), which is a powerful framework to define, characterize, guide, monitor and assess progress towards SFM in a given context (ITTO, 2016). Principles are statements of goals or values that provide a crucial foundation for SFM. They form the basis for defining criteria and specific indicators for monitoring. Since the first set of PC&I developed by the International Tropical Timber Organization (ITTO) in 1992, it has gone through different modifications (Martn-Garca & Diez, 2012). CFUGs must design their PC&I by considering local circumstances (including resource availability and capacity), SFM objectives, applicable laws, practices and guidelines.

3.2.2. Assessment of mitigation outcomes

Although SFM encapsulates mitigation contributions in many ways, assessing mitigation outcomes can be complex and thus requires familiarization of additional steps. For instance, mitigation contributions, such as from REDD+, should undergo MRV that complies with an international standard to be eligible for results-based payment (UNFCCC, 2014). MRV is essential for the recognition and visibility of action undertaken by CFUGs.

Capacity gaps remain for actual implementation since mitigation activities will mainly take place at the community forestry level. One of the suggestions in the workshops was to empower CFUGs to conduct community-level carbon accounting while the responsible government agencies conduct additional tasks that are not effective/pragmatic at the community level (such as processing of satellite data) at least in the early stages. Community-based forest biomass monitoring (CBFBM) can be employed as it relies on a participatory approach that enables the community to drive and own the monitoring process with or without external guidance and facilitation (Edwards, Scheyvens, Stephenson, & Fujisaki, 2014). CBFBM aims to build the capacity of communities to conduct monitoring in a reliable manner using scientifically proven methods and tools, which typically are left in the hands of forest professionals. A combination of scientific and local/traditional methods is the real advantage of CBFBM as it ensures that the whole monitoring process is compatible with the local specificities and available resources.

3.2.3. Assessment of adaptation outcomes

A major and evolving concern are the impacts of climate change on forests that could have far-reaching impacts on the sustainability of forest ecosystems. Forests can be affected by a variety of climate change-induced natural causes and anthropogenic actions such as encroachment, illegal harvesting, wildfire, animal grazing, mining and construction, the spread of invasive species, pests and diseases, impacts of extreme weather events (e.g. heavy rainfall, flooding and drought), etc. Communities need local approaches to monitor vulnerability and threats on forests and on dependent livelihoods enabling them to plan adaptation measures to enhance the resilience of forest ecosystems and dependent communities.

For the implementation of NDCs, monitoring and assessment are critical for examining the effectiveness of adaptation measures as well as for achieving the necessary balance with mitigation activities. Communities can identify, select and monitor a set of indicators that are specific to the risks or vulnerability of their community forestry. To assess the effectiveness of adaptation measures, the global goal on adaptation (under Article 7) of the Paris Agreement identifies three major criteria: enhancing adaptive capacity, strengthening resilience and reducing vulnerability. Under these criteria, communities can establish a monitoring process by listing key impacts on forests and the community and determine relevant indicators for each impact. Communities can identify and select adaptation measures to address identified impacts and then evaluate the effectiveness of implemented adaption measures on these criteria.

3.2.4. Assessment of quality of governance

Ensuring good governance is critical for the effective implementation of projects, programmes and actions related to NDCs commitments. The realization of outcomes related to SFM, mitigation and adaptation largely depends on the quality of governance. Governance is multifaceted and comprises of coordination, clear roles and responsibilities, participation, information availability, inclusiveness, transparency and accountability, customs, the rule of law and decision making, mechanisms for fair distribution of incentives (cost, penalty, sanctions and benefits) between and among different jurisdictional levels. Governance is relevant to the NDCs as these cover the decisions, actors, processes, arrangements and policy tools needed to design and to implement climate action. Governance involves local, national and global actors from a wide range of sectors and relates to the institutional, policy and legal dimensions that will influence the successful implementation of climate action.

Since it is often difficult to quantify governance, a common standard for measuring the quality of governance is important at the community level. Expressing the quality of governance at the community forestry level recognizes the joint efforts by stakeholders to improve SFM practices, including effective climate action. Community forestry can also establish and apply a hierarchical approach based on PC&I in a participatory manner to assess the quality of governance. Participants at the capacity assessment workshops concluded that the use of a standard approach is feasible and useful in trials of the PC&I framework to access the quality of governance using principles of meaningful participation (as a governance structure) and productive deliberation (as a process) (Lopez-Casero et al., 2016). Again, capacity building, with the involvement of government and experts, is a key to design a local standard and ensure the effectiveness and usefulness of the governance assessment process.

It is evident that assessing SFM, mitigation, adaptation and quality of governance will involve overlaps. Given the increasing number of processes and limited resources, capacity building is particularly important to streamline all assessments and avoid redundancies. To this end, CFUGs can adopt a cross-referencing process to identify common indicators or verifiers that will fulfil more than one criterion and integrate them into a single process to assess multiple outcomes. The exercise will streamline all monitoring activities so that communities can use a single MRV using the PC&I approach to assess the outcomes and performances.

3.3. Integrated planning and implementation

An IP&I is indispensable to incorporate additional actions related to SFM, climate action and governance. IP&I will help in assessing the resources needed to allocate division of roles and responsibilities and identify needed external support for finance, technology and capacity development.

Since a participatory approach is key for IP&I, a mapping of all stakeholders involved is key for effective coordination. Communities should objectively conduct stakeholder mapping to allocate appropriate roles and responsibilities based on capacity, position and benefit/burden-sharing, which is also useful in examining the level of coordination required both horizontally and vertically.

Implementation of SFM activities and climate action necessitate substantial human, financial, technical and institutional resources and capacity. Communities, therefore, need to plan their activities using available resources and capacity. The assessment helps to identify resources and capacity gaps and hence determine the feasibility of planned measures. Furthermore, it helps to build a strategy for seeking external support from government and non-government sources based on actual need. This strategy can significantly help communities to decide what kind of support to receive and what to decline.

IP&I of SFM, mitigation, adaptation or governance is an adaptive process that involves continuous learning and improvement. An iterative approach like a PDCA (Plan, Do, Check and Act) cycle can be used. Although PDCA appears as an additional part of the planning process, the objective here is to prioritize action that communities can accomplish with the resources and capacity available to them. The focus is on gradual improvement in the performance of the PDCA cycle in the current year, although this is guided by long-term vision, goals and objectives. A stepwise approach provides valuable learning opportunities to communities, which is fundamental for adaptive planning.

4. CONCLUSION

Forests are strategic resources for tackling climate change problems and realization of the commitments in NDCs. Given that forests are a complex SES, targeting climate action without considering sustainability, community participation, rights, socio-economic and environmental concerns, will not be effective. There remain genuine capacity concerns at the community level regarding understanding roles and responsibilities, cost-benefits, know-how and skills, and planning and implementing climate action. The action research identified the needs of capacity building to ensure that communities are engaged in the processes to integrate SFM, mitigation, adaptation and quality of governance for synergistic outcomes as well as to safeguard long-term interests. A comprehensive framework of capacity building at the community level, such as the one proposed in this paper, is necessary by integrating planning, implementation and assessment of key outcomes to translate NDCs commitment into actions, ensuring meaningful participation of CFUGs and facilitating enhanced communication to mainstream local action into national and international processes.

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Technical report

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Co-production of knowledge and transformative learning towards a sustainable Asia

Mochamad Indrawan [a] [*], **Dicky Sofjan** [b]

[a] Research Center for Climate Change (RCCC), FMIPA - Faculty of Sciences, Universitas Indonesia, Depok, Indonesia
[b] Indonesian Consortium for Religious Studies (ICRS), Graduate School of Universitas Gadjah Mada (UGM), Yogyakarta, Indonesia
[*] *Corresponding author. Email: mochamad.indrawan@gmail.com.*

ABSTRACT

In Asia, sustainable development has yet to find its critical mass. Non-state actors have the opportunity to catalyze change by awakening their collective consciousness through mutual learning and shared experiences. Initiated by Chulalongkorn University in Bangkok and the Indonesian Consortium for Religious Studies (ICRS) in Yogyakarta, a civic engagement project—involving partners and networks in Southeast Asia and Japan—was created to capture sustainable development initiatives from the ground, with a view towards strategic policy advocacy for a more sustainable Asia. The project aimed to bridge knowledge gaps by bringing together all relevant state and societal stakeholders to learn from one another and share their experiences, stories and narratives about change and self-transformation. Through a series of workshops, focus group discussions (FGDs), NGO fora and mayors' symposia since 2015, the project resulted in an accumulation of knowledge that has the potential to galvanize the various efforts to push the sustainable development agenda forward on the ground. The collaboration of many partners and relevant stakeholders overall met its intended outcome by generating an ad hoc centre for the co-production of knowledge on sustainability and a "transformative learning" platform. This was achieved by acknowledging the existence of various systems of knowledge, disciplines, and occupations while appreciating the tacit knowledge and unique insights coming from all participating partners, including the mayors, regents and local officials, and their civil society counterparts.

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KEYWORDS

Sustainable development, Asia, Civic engagement, Co-production of knowledge, Transformative learning, Mayors' symposium

HIGHLIGHTS

- This collaborative project addressed a lacuna in civic engagement and aimed to strengthen the co-production of knowledge on sustainability and crystalize the process of transformative learning among the stakeholders in the region.
- One of the key strategies was to facilitate the building of a platform that could facilitate a meaningful interface between local authorities such as mayors and regents and their development counterparts, including civil society.
- Through the co-production of knowledge and transformative learning, the project team generated many deep reflections and new insights into the inner workings of sustainability (Mezirow, 1991).
- The inspiring stories and narratives of change were conveyed in an edited book, policy briefs, and a monograph written by NGO activists, expert practitioners, scientists, and public intellectuals from the region.
- Co-production of knowledge provides the coming together of ideas and visions of people from different backgrounds and institutional affiliations.

1. INTRODUCTION

The concept of this project came from the growing concern among public intellectuals in Asia regarding the challenges of sustainability facing the region and the world. Public intellectuals were witnessing chronic disconnections among the regions' state and non-state actors such as national policymakers and local governments, academic institutions and civil society, including local grassroots communities. This is not to mention the international community, which has its own normative thinking, policy infrastructures and worldwide strategy through the proliferation of the Sustainable Development Goals (SDGs).

The project aimed to bridge knowledge gaps by bringing together all relevant state and societal stakeholders to learn from one another and share their experiences, stories and narratives about change and self-transformation. This approach allowed various stakeholders, both from the region and beyond, to co-produce knowledge on sustainability while transforming their thinking and learning about the issues from a multitude of perspectives, disciplines and unique experiences. In the field of sustainability, co-production of knowledge is viewed in a general way as part of a gradually developing group of approaches, including transdisciplinary and joint knowledge production, participatory research, interactive research, action research, civic science, post-normal science, translational ecology and engaged scholarship (*inter alia* Gibbons et al., 1994 and Norström, 2020). Such an inclusive and participatory approach laid the groundwork for robust scientific outputs and strategic outcomes for the region. Inadvertently, this has facilitated a sense of collective consciousness, allowing mental and intellectual flexibility in advocating and mainstreaming sustainable development policies and outcomes across Southeast Asia and Japan.

In realizing these goals, emphasis was placed on a mutually transforming learning process. We applied Mezirow's rationale that at the heart of "transformation" rests a wise interrogation of deeply-held assumptions and perspectives. To allow for such adequate "learning", a shift in perspective would require open exchanges among peers, while guided by the quest for meaning and for legitimate solutions—rather than by the instructions of the market or the state— therefore orienting towards action (Wun'gaeo, Indrawan, Luzar, Hanna, & Mayer, 2020).

2. METHODS

In order to showcase sustainable development innovations from the ground, the project was informed by the tacit knowledge of stakeholders, the various scientific enterprises by academics and researchers and the unique experiences of multifarious civil society actors. A series of reflections, discussions and documentation were enabled through the collaboration of civil society leaders from Southeast Asia and Japan, whereby they began the process of synthesising various on-the-ground sustainable development issues and solutions.

In 2015, the regional project "Transformative Learning Towards a Just and Sustainable ASEAN Community", led by Chulalongkorn University, launched a series of events. Later, these were connected to the Bangkok Forum held in 2018, where Chulalongkorn University raised the issue of future "social sustainability in Asia". Around 800 participants, including dignitaries of strategic world organizations and young people from around the world, attended the Bangkok Forum.

Together with Chulalongkorn University, ICRS hosted a regional workshop entitled "Civic Engagement for a Just and Sustainable ASEAN: Our Stories and Practices" in Yogyakarta, Indonesia, on 11-14 August 2017. This event was followed by a subsequent event entitled "Civic Engagement 4.0: Justice, Dignity and Sustainability" on 19-23 August 2019 in Solo, Central Java, Indonesia, which comprised an NGO forum and a mayors' symposium. Soon after, another major event took place in Denpasar, Bali, on "Co-Designing Sustainable, Just and Smart Urban Living" on 6-8 April 2021, which mainly emulated the Solo activities. However, due to the COVID-19 pandemic, social restriction measures, the Bali events were convened in a hybrid format, allowing participants, including mayors and regents, to participate through an online platform.

While the participants in the first major event comprised around 25 high-level individuals, the latter two events involved hundreds of participants, including grassroots community leaders. Over 30 organizations from Southeast Asia, Japan, Canada, the USA, Australia, the UK, Kenya and other countries participated actively in the event. They shared their research, reflections, thoughts, experiences, stories and narratives on sustainability. Participants of the latter two events also included around 20 mayors, regents and representatives of local governments from Indonesia, Thailand and the USA. Some of the leading questions and issues raised in these events included the following:

- What are the main problems or issues of sustainability perceived by civil society in the Asian region? What are the key strategies and methods of engagement to interface with the national and local governments? Who or what are their primary targets?
- What are some of the internal and external factors and circumstances that have helped facilitate (or limit) these desired changes in the short- and long-term? What are some of the desired attitudinal, social and policy changes? How are these changes 'measured' and assessed?
- What about social justice, inclusion and gender? How could they be incorporated into the thinking and strategies of sustainability?
- How do governance and leadership play a role in pushing the agenda for sustainability in cities and regencies? What sustainability transition policies are in place? And how could civil society take a proactive role in the whole endeavour?

The above list comprised open-ended questions that we anticipated would not be fully answered in one or two workshops or a conference. However, the deliberations and interface among the stakeholders placed a high premium on the co-production of knowledge and transformative learning, where individuals, groups and organizations then depart with new realizations, knowledge, perspectives and a refreshed outlook in life and living.

Furthermore, local stories and narratives tend to be more appealing than the usual global normative mantras, such as the SDGs with their 17 targets and 169 target indicators. This was aptly summarized by Vannarith, Yin, and Mayer (2020), who wrote, "Successful on-the-ground resolution by a local group will provide a model to be studied, emulated, and applied by others – which may be in different localities but happened to be in a similar situation."

3. RESULTS

The knowledge products included an edited volume, two policy briefs, a monograph and a series of public and media outreach activities. The primary readership of the book includes regional policymakers, scientists, scholars, youth and practitioners endeavouring to consider sustainable development within the Asian context for potentially creative and transformative processes led by concerned citizens and activists at the grassroots level.

3.1. The book

The edited volume, entitled Civic Engagement in Asia: Transformative Learning in The Quest for a Sustainable Future, comprises 24 chapters, which capture sustainability practices around the region (Wun'gaeo et al., 2020) (See Figure 1 and Table 1). The chapters address topics such as resilient cities and sustainable urban planning, natural resources management and social enterprise, social and religious harmony, disaster mitigation and human trafficking, capacity building and networking support for civil society groups, knowledge creation and sharing, and leadership sharing (Vannarith et al., 2020). The diversity of issues was displayed through reflections on indigenous peoples and local communities, youth, women, artisans, volunteers, labour workers, teachers, students and religious communities, characterized by multi-year collaborative knowledge production and civic activism (Hapsari, Sofjan, & Mayer, 2021).

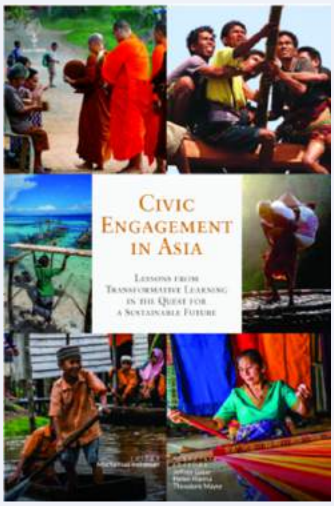

FIGURE 1. Edited volume resulting from the first civic engagement series discussions culminatingin a 2017 workshop in Yogyakarta.

3.2. Policy briefs

Two outputs from activists from the ASEAN member countries have already been completed in 2021:

- **Biodiversity Conservation and Culture Nexus are Worthy of Local Economic Development**, which takes the case of supporting woven clothing made by women artisans from East Sumba (Indonesia), emphasizing that capitalizing on the nexus between biodiversity and culture could help a district to become a prosperous and iconic responsible travel destination (Kirana, 2020).
- **Dealing with Contamination: The Thailand Perspective** - advocating a response to the toxic waste issue through reformed law and resolutions, and remediation measures (Saetang, 2020).

3.3. Monograph

A forthcoming monograph reflects on the process of the NGO fora and mayors' symposia (Sofjan et al., in press) held in 2019 and 2021. The monograph makes mention of the need to meaningfully

Chapter	Title	Authors
1	Building Livelihood Sovereignty for the Mekong Region	Tran Thi Lanh
2	Building Recognition for the Resource Rights of Indigenous Peoples and Local Communities	Antoinette G. Royo, Andhika Vega Praputra, Joan Jamisolamin, Neni Rochaeni
3	The Heartware of Ecological Sustainability in the Asian Context	Dicky Sofjan
4	Transformative Learning for Thailand's Small-scale Farmers	Supa Yaimuang
5	The Role of Citizen Science in Policy Advocacy & Building Just and Ecologically Sustainable Communities in Thailand	Penchom Saetang
6	Creating an Enabling Environment for Lao Youth to Engage with the Community Development Process	Khamphoui Saythalat
7	How Biodiversity and Culture can Fuel Economic Prosperity: the Case of Traditional Textile Artisans of East Sumba, Indonesia	Chandra Kirana
8	Localizing the Sustainable Development Goals: The Case of a Community in Quezon City, Philippines	Nestor Castro
9	Facilitating Household-level Biogas Production: a Case Study From the Indonesian Island of Lombok	Niken Arumdati
10	Urban Reform in Indonesia	Ahmad Rifai
11	A Decade of Fighting Box Jellyfish Health Issues	Lakkana Thaikruea
12	Citizens' Initiatives in the Fukushima Radiation Disaster: Measuring and Sharing Fukushima	Mariko Komatsu
13	Democracy in the Wake of the Fukushima Nuclear Disaster	Hiroko Aihara
14	Fighting Modern Slavery in Southeast Asian Waters	Sompong Srakaew & Patima Tungpuchayakul
15	Female-driven Climate and Environmental Action: Champions from Pakistan	Areej Riaz & Mairi Dupar
16	Development Challenges in Papua and West Papua	Alex Rumaseb
17	In These Troubled Times, Could Every Classroom Become a Site of Transformation? The Story of the SENS Program	Theodore Mayer
18	SENS and Its Impacts on Me: A Reflection from Karbi Anglong	Sabin Rongpipi
19	SENSing the Truth amidst a Crisis at the Personal, Social, and Environmental Crisis Levels: Learnings and Contributions Towards Sustainable Development in India in India	Mahesh Amandkar
20	Sustainability and Communities of Faith: Islam and Environmentalism in Indonesia	Fachruddin Majeri Mangunjaya & Ibrahim Ozdemier
21	Policy Entrepreneurship for Sustainable Development in Malaysia: A Reflection	Hezri Adnan
22	Step by Step from Cambodia Towards ASEAN	Heng Monychenda
23	Reflections on Civic Engagement and Key Issues	Chheang Vannarith & Maung Maung Yin
24	Civic Engagement for a Just and Sustainable ASEAN	Erna Witoelar

TABLE 1. Table of contents of the edited volume

engage the issues of sustainability, human dignity, social justice and smart cities while stressing the importance of transformative learning, open governance, democratic governance and servant leadership in civic engagement.

3.4. Further outreach

Further outreach and advocacy were undertaken through international conferences, including book discussions and a virtual book launch and discussions.

- "Community, Ecology and Religion: Interdisciplinarity and Civic Engagements towards Sustainable Living" in the 4^{th} International Conference of Interreligious and Intercultural Studies (ICIIS) at Universitas Hindu Indonesia, Denpasar, Bali, on 15 February 2020. See: https://www.apn-gcr.org/news/civic-engagement-in-asia-book-launch-held-in-indonesia/

- Virtual International Webinar and Book Discussion, organized by Universitas Indonesia – Faculty of Mathematics and Sciences, 28 August 2020
- Virtual International Webinar and Book Discussion, "Promoting Environmental Sustainability Through Social Science Perspective" in 2nd International Conference on Social Science Education, organized by Universitas Lambung Mangkurat on 23 September 2020. See: https://www.icsse.ulm.ac.id
- One media article from a well-known portal, namely Mongabay in Indonesia. See: https://www.mongabay.co.id/2021/03/09/masa-depan-berkelanjutan-di-asia-pasca-covid-19-berkaca-dari-pengalaman-aktivis-lokal/

4. DISCUSSION

We consider the uniqueness of our approach rests in its iterative approach to delve into both concept and practice of civic engagement. Our probe was advanced through the series of regional dialogues: "Transformative Learning Towards a Just and Sustainable ASEAN Community" (Yogyakarta, 2015), "Bangkok Forum" (2018), "Civic Engagement 4.0: Justice, Dignity and Sustainability" (Solo, 2019), "Co-Designing Sustainable, Just and Smart Urban Living" (Denpasar, 2021). While it may be too early to establish sustainability outcomes from the project beyond a reasonable doubt, our progressively inclusive multi-stakeholders discussions did allow and, in fact, facilitated the clashing of cultural assumptions and interrogations of deeply embedded beliefs and perspectives. The co-production of knowledge and co-designing process, along with the search for meaning and genuine solutions, helped improve the focus towards a wise and balanced form of collective action.

The series of regional, participatory and meaningful exchanges has set in motion a kind of "transformative learning" in Mezirow's parlance while simultaneously demonstrating the serious allocation of time, energy, investments and resources over an extended period of time by the various actors, partners and stakeholders. This attested to their commitment and propensity for change in the right direction.

4.1. The building of momentum

The NGO fora, held twice in Solo (2019) and Bali (2021), connected the intricate and complex web of civil society actors in the region working on sustainability. A mix of civil society actors, ranging from environmental activists to faith communities, youth leaders, disabled and women's groups, all participated in knowledge-sharing and storytelling. Their interface with mayors and regents in the two symposia also provided a glimpse of the power and positive role of civil society in aiding local governments to confront the challenges of sustainability while at the same time providing development solutions.

At least three principles emerged due to the two mayors' symposia: open governance, servant leadership and the role of faith in urban resilience. Open, democratic governance refers to the idea that managing development and change constitutes a collective endeavour, requiring inputs, feedback and criticisms from all concerned parties and stakeholders. The imperative for openness in democratic governance would ultimately lead to greater transparency, inclusion and meaningful civic engagement. Servant leadership suggests a mode of change from below. The idea that mayors and regents are mere servants of the people is not new but hardly articulated in contemporary times, most notably in Asia. Therefore, servant leadership denotes the willingness of the government to 'listen' attentively to the voices on the ground and the constructive criticisms on a wide range of governance issues. It also assumes that governments would, in all earnestness, respond to them favourably.

The third principle concerns the role of faith in urban resilience, which seems counter-intuitive to many. The World Urban Agenda (WUA) from

UN-Habitat, for instance, does not make any mention of faith, religion or spirituality. Its underlying assumptions likely foresee urban centres as wholly secular. This assertion is, of course, baseless. In the United States of America, according to a Gallup Poll survey conducted in 2011, "more than nine in 10 Americans continue to believe in God". Meanwhile, most people in Western Europe say they "believe in God" although "believing in God does not necessarily mean belief in the God of the Bible" (Cooperman & Sahgal, 2018). To assume that religion, faith and spirituality are irrelevant to sustainability seems to hold no logic or scientific prudence. In fact, based on The Future of World Religions: Population Growth Projections, 2010-2050 (Hackett et al., 2015), it is said that "Muslims are rising fastest and the unaffiliated are shrinking as a share of the world's population". This only goes to show that religion or faith communities are perhaps the most sustainable human institutions ever to exist and flourish, until today.

4.2. Co-production of knowledge

In order to achieve impact, a book must be effectively distributed. The latter is a function of pricing and distribution range. We originally planned to publish one book through a reputable education-oriented publisher (Yayasan Pustaka Obor, Indonesia) to allow commercially friendly access. Fortunately, Springer also showed interest in republishing and distributing the book worldwide.

As intended, the edited volume managed to showcase the contributions of non-state actors on the ground and inadvertently highlighted the years of transformative learning that has unfolded and benefited those who participated in the various events held throughout the past five years. As beautifully commented by the reviewer to the Springer edition (Indrawan, Luzar, Hanna, & Mayer, in press), Dr Julian Caldecott:

"The community orientation is consistent and strong, reminding us that our lives really only make sense in a social and ecological context. The result is that the book bears comparison with the foundational volume The Wealth of Communities: Stories of Success in Local Environmental Management by Pye-Smith, Borrini, and Sandbrook (1994). This places it within a current renaissance of appreciation for community-based environmental management, which is fast becoming prominent as a key way for societies to adapt to climate change and ecological chaos."

As pointed out by Hapsari et al. (2021), civic engagement is, after all, a political project that calls for the ability to deal with both structural and cultural challenges to the sustainability agenda, of which civil society actors provide an important lever. In effect, civic engagement in sustainability can provide a strong nexus of ideas and discourses as long as platforms are continually built around the subject matter. Due to the nature of sustainability being an all-encompassing norm, the co-production of knowledge and transformative learning, which stress the importance of proactive and deep listening, could be held as a basic premise to meaningful civic engagement. Evidence from the project suggests that sustainability in Asia could be attainable if all partners and relevant stakeholders were engaged in a mutual learning platform to reflect on their tacit knowledge, experiences, local stories and narratives. Effective collaboration and synergy among actors and participants are most certainly needed to ensure that sustainable development learning takes place across local communities throughout Asia.

5. CONCLUSION

Through a series of workshops, focus group discussions, NGO fora and mayors' symposia, followed by publications and write-ups by project participants, new knowledge, inspiring stories and narratives related to SDGs on the ground have emerged as part of the collective consciousness of those who are pro-actively supporting and promoting sustainability in the region. The realization and crystallization of a new 'movement' in the region, which is dedicated to sustainability in and of itself, is undoubtedly a positive development and trajectory in Asia that needs to be acknowledged and appreciated.

The question of whether or not such movements would sustain themselves is a different issue altogether. At the very least, though, participation of multi-stakeholders, including local decision-makers and civil society actors, provided a clear message that in meeting the common goal of sustainability, there are contexts, multiple interests and approaches to every issue, all of which may be interwoven and strengthened by active engagement and mutual learning among the relevant actors and stakeholders. Yet clearly, the outputs and outcome of the project have given us the much-needed empirical perspective, hope and confidence in the future of co-production of knowledge and transformative learning in the region.

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Original research

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Integrated highland wildfire, smoke, and haze management in the Upper Indochina region

Kobsak Wanthongchai [a] [*], **Veerachai Tanpipat** [a], **Prayoonyong Noochaiya** [b], **Nion Sirimongkonlertkun** [c], **Ronald Macatangay** [d], **Lattana Thammavongsa** [e], **Thaung Naing Oo** [f], **Sherin Hassan Bran** [d], **Raman Solanki** [d]

[a] Upper ASEAN Wildland Fire Special Research Unit, Faculty of Forestry, Kasetsart University, Chatuchak, Bangkok, Thailand
[b] Department of National Park, Wildlife and Plant Conservation, Chatuchak, Bangkok, Thailand
[c] Rajamangala University of Technology, Chiang Rai, Thailand
[d] National Astronomical Research Institute of Thailand, Chiang Mai, Thailand
[e] Department of Forestry, Ministry of Agriculture and Forestry, Vientiane Capital, Lao PDR
[f] Forest Research Institute, Forest Department, Ministry of Environmental Conservation and Forestry, Nay Pyi Taw, Myanmar
[*] *Corresponding author. Email: fforksw@ku.ac.th.*

ABSTRACT

Fire has long been used in Southeast Asia for the purposes of cooking, protection, and warmth. However, climate change and economic pressure have modified the life of locals, including fire practices in daily life and other fire uses. The land use of forest cover in highland area (mostly deciduous forest) has shifted to cultivation, with the application of slash-and-burn techniques. This results in frequent unplanned fires causing pollution in the form of smoke and haze. A zero-burn policy has been implemented to tackle this problem but such a policy may not be appropriate as people still need fire as a basic tool for agriculture land preparation. Moreover, the deciduous forest is a fire-dependent ecosystem to maintain its ecosystem. Frequent burning by local people or excessive government intervention in preventing fires can impact this ecosystem. In the highlands, shifting cultivation has gradually been replaced by rotational agricultural practice with a cycle of 2 to 5 years. However, the fuel load for a 2-year rotation period is only 0.25 t ha^{-1} higher than that of a mixed deciduous forest. New fire risk maps classified according to forest types were produced for Thailand, Lao PDR, and Myanmar. We report that the mixing layer (ML) height in Chiang Mai Province was, on average, 500 m during March, with common occurrence of subsidence inversion resulting in further lowering of air quality during this month. A participatory process to develop a Community Based Fire Management (CBFiM) was undertaken and it was observed that a successful implementation would need a community with a strong leadership.

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KEYWORDS

Highlands, Rotated Agriculture, Fuel Load, Fire Risk Maps, Mixing Height, CBFiM

HIGHLIGHTS

- A better understanding of fuel load and fire behaviour in the highlands of upper ASEAN Region.
- Fire risk maps for Thailand, Lao PDR, and Myanmar.
- Short-term air quality forecast for the Chiang Mai Province.
- Good community-based fire management practices.
- International collaboration between Thailand, Lao PDR, Myanmar and Asian Forest Cooperation Organization (AFoCO).

1. INTRODUCTION

Fire has long been used in Southeast Asia for purposes of cooking, protection and warmth. However, climate change, population increase and economic pressures have changed the way locals live, in terms of fire rituals practiced in their daily life, its cultural uses or the way indigenous people use fire for their livelihood, such as using fire for gathering non-timber forest products, using fire to clear land for agriculture, etc. Forests are burned too frequently to harvest non-timber forest products (NTFPs). The land use character of highland areas has been gradually changing from forest cover (mostly deciduous forest) to shifting cultivation, in which the slash-and-burn technique is readily applied. Subsequently, crop rotation practice has been employed in such locations, where a few fixed plots will be used over the coming years. This has led to frequent unplanned fires and hence air pollution caused by smoke. For example, most forest fires lit in the highland areas of northern Thailand are for harvesting of NTFPs and open burning in fields practicing monoculture, such as maize. This creates air quality problems during the fire season between February and April, with the peak burning period in March. In Thailand, a zero-burn policy with a prohibited burning period has been enforced to tackle this problem. However, this policy may not be appropriate, since people still need fire in agriculture, as it is the cheapest way to clear the land and prepare it for the next crop. However, the last forest fire in 2019 indicated to the ill-effects of this practice, when, unfortunately, more unplanned fires led to conflicts between locals and government authorities. Moreover, the deciduous forest is a fire-dependent ecosystem; frequent burning by locals or too much intervention by the government policy can impact this ecosystem. This project adopts an Integrated Fire Management (IFM) system with a participatory process involving people to develop a Community Based Fire Management (CBFiM) plan. To achieve this target, fuel and fire behaviour, fire impact, fire risk map derived from fire meteorology and air pollutant emissions, climatology, modelling, and climate change scenarios were evaluated. Community participation is an essential factor while considering the aforementioned information for developing a suitable and sustainable CBFiM plan.

2. METHODOLOGY

2.1. Sampling of plots to study fuel and fire behaviour across various land use types

Pre-burned fuel characteristics were complied selected in a swidden farm (with 1- and 5-year fallow periods), a corn farm, upland rice farm, an abandoned highland (natural restoration area) and a mixed deciduous forest in Nan and Huai Kha Kang (HKK) Forest Fire Research Center, Thailand. Fuel loads in the 1- and 5-yr swidden farms comprised of litter and herbs, as well as trees and shrubs given that the agricultural practices employed in the highland areas. Such slash and burn practices result in the cutting and burning of these woody plants. Therefore, we included the woody plants as available fuel. The quantity of fuel was estimated using the equations of Tsutsumi, Yoda, Sahunalu, Dhanmanonda, and Prachaiyo (1983).

Fire behaviour experiments were set up to determine the flame length, rate of fire spread, and fire intensity based on the equations recommended by Byram (1959), whereas forest fuel and corn stubble heat values were obtained from Sompoh (1998) and Lizotte, Savoie, and Champlain (2015), respectively.

2.2. Highland fire risk map across northern Thailand, Myanmar, and Lao PDR

Data needed for the construction of fire risk maps for the highlands in the upper ASEAN region were compiled from various sources. These included the Land Cover Product from the European Space Agency Climate Change Initiative, Active Fire Products from NASA-FIRMS (National Aeronautics and Space Administration-Fire Information for Resource Management System), Global Forest Watch Fire by the World Resources Institute, Global Forest Change data maintained by the Department of Geographical Science, University of Maryland, MCD64A1.006 MODIS Burned Area Monthly Global 500m by EarthMap-FAO, and Fire emissions derived from the Fire Radiative Power (FRP) product of the European Centre for Medium-range Weather Forecasts (ECMWF)—Copernicus Atmosphere Monitoring Service (CAMS)—Global Fire Assimilation System. Data was then regrouped into similar classes to simplify the land cover maps and projected on to the country's land cover map. MODIS active fire products from 2001 to 2019 were separated based on various satellites, years, and months, to determine the fire regimes and fire ignition patterns. The Mosaic and Global Land Analysis and Discovery (GLAD) Forest 'loss year' products during the years 2001-2018, were used to observe the forest loss patterns. Lastly, the data was analyzed and risk maps by forest type were created.

2.3. Understanding the meteorology and air pollutant emissions from fire in the study domain through climatology, measurements, modelling and climate change scenarios

The atmospheric boundary layer, also referred to as the planetary boundary layer or mixing layer (ML), is a turbulent layer located at the lowest part of the atmosphere that is in a constant state of exchange (i.e., diurnal cycles of heat, water vapour, and pollutant exchange) with the surface of the Earth (Stull, 1988; Seibert, 2000). The temporal response range usually lies within a scale of an hour or less.

Estimating the height of the ML can be done using Light Detection and Ranging (LiDAR). LiDAR operates by shooting a pulsed laser of particular wavelength (in this case, a wavelength of 532 nm) vertically into the atmosphere. Backscattering occurs when the laser pulse encounters aerosols, particulates suspended in the atmosphere, or clouds, with the number of photons, as a function of height or altitude (range), detected by the ground system. The number of photons detected is proportional to the aerosol content along the light path of the laser.

The study utilized a mobile atmospheric micropulse LiDAR owned and operated by the Atmospheric Research Unit of the National Astronomical Research Institute of Thailand (ARU-NARIT or ARUN), located at the NARIT headquarters in the Maerim district of Chiang Mai, northern Thailand (18.8510° N, 98.9580° E, 472 masl). It has been operational at the given location since April 2017 and has been part of the NASA Micropulse LiDAR Network (MPLNet) since August 2018 (https://mplnet.gsfc.nasa.gov/data.cgi?site=Princess_Sirindhorn_AstroPark).

From February-September 2019, the micropulse LiDAR was relocated to the Fang district, in north of Chiang Mai, northern Thailand (https://mplnet.gsfc.nasa.gov/data.cgi?site=Fang; 19.9110° N, 99.2020° E, 472 masl) near the border of Myanmar (approximately 14 km) and in proximity to Lao PDR (approximately 100 km), as a part of the profiling with LiDAR and UAV Multi-scale Experiment (PLUME) and the Spring 2019 Seven Southeast Asian Studies (7-SEAS) measurement campaign in March 2019. Apart from the atmospheric LiDAR instrument, PLUME partners from the Department of Atmospheric Science of the National Central University of Taiwan also deployed black carbon measurements onboard a UAV. In this research, the height of the ML was estimated using the Haar Covariance Wavelet Transform (Brooks, 2003; García-Franco, Stremme, & Bezanilla, 2018), which is a de-noising and gradient detection method wherein it estimates the ML height by determining the altitude at which there is a maximum gradient of the LiDAR backscatter signal.

A lecture was also presented regarding this topic during workshops organized by the proponents.

2.4. People's participation in the management of fire and smoke using concepts of Integrated Forest Fire Management (IFFM)

We used a desktop study and literature review to gather documents, information, publications and evidence about the history of the community, their traditions and way of life. In addition, participatory observation was used to observe the conditions of the study areas and the community activities related to the management of forest fire. We also conducted in-depth interviews to understand and assess the lessons learned from the community about forest fire and haze management. Focus group discussions were organized, where the target audience (i.e., the sub-district headmen, village headmen, community leaders and youth leaders) were asked about their awareness of forest fire and haze pollution and their roles or participation in addressing the problem, together with support from the government sector and civil society organizations. Informal dialogues took place during discussions with the community members and the interviewers would ask for more detail, if any interesting topics related to forest fire management came up.

3. RESULTS AND DISCUSSION

3.1. Fuel and fire behaviour in sample plots across various of land use in the highlands

Common agricultural practices in the highlands include swidden farm agriculture using slash-and-burn practices. Upland rice growing is the most important cash crop for the swidden farms. All vegetation is duly cut before the commencement of the cropping season (January-February). The burning period usually starts around early March for the preparation of land. Prior to burning, farmers apply firebreaks around the land and ask for the assistance of the forest fireguards in controlling the fire. Burning is, therefore, safely operated through this controlling strategy. Usually, villagers cultivate rice for 1 to 2 growing seasons and then leave the land for a couple of years. In the past, the period of rotation used to be seven years, but the fallow period was shortened to 2 to 5 years due to a limited availability of agricultural land. As for other cash crops, such as corn and cabbage, the villagers do not leave the land fallow for any period anymore. We observed that semi-permanent agriculture is adopted for corn and cabbage cultivation in the highland areas of Thailand. After harvesting, the farmers leave the agricultural residue (stubble) on the land and burn it when the weather and fuel conditions are favourable.

3.1.1. Fuel characteristics

The study demonstrated that above-ground pre-burned fuel structures on the corn farm and the mixed deciduous forest consisted of both litter and undergrowth. Fuel loads in the corn farm were composed of 3.59 t ha^{-1} of stubble litter and 0.27 t ha^{-1} of undergrowth, with a fuel height of 0.34 m and 0.41 m, respectively. On the other hand, fuel in the mixed deciduous forest comprised 3.34 t ha^{-1} of litter and 0.23 t ha^{-1} of undergrowth with an average fuel height of 0.30 m and 0.43 m, respectively. Undergrowth contributed the most to the available fuel in the swidden farms, abandoned areas and upland rice farms. Interestingly, the 5-year swidden farm had a very large amount of fuel load (110 t

Study site	Land use	Fuel height (m)		Pre-burned fuel (t ha^{-1})		
		Litter	Undergrowth	Litter	Undergrowth and tree	Total
Nan province	Corn farm	0.34±0.12	0.41±0.02	3.59±0.49	0.27±0.50	3.86±0.47
	Upland rice farm	NA	0.48±0.08	NA	2.665±0.49	2.665±0.49
	1-yr swidden farm	0.14±0.05	2.18±0.38	3.00±0.26	7.9375±2.01	10.93±2.89
	5-yr swidden farm	0.19±0.09	0.35±0.08	3.625±0.36	106.75±35.28	110.37±48.41
	Abandoned highland	0.15±0.05	2.54±1.95	17.83±1.22	33.26±13.52	51.10±16.25*
	Mixed deciduous forest	0.12±0.04	0.43±0.14	3.34±0.29	0.23±0.15	3.57±0.39*

Remark: * trees were not included. NA implies not applicable.

TABLE 1. Fuel characteristics in the highland areas of Thailand.

ha^{-1}), whereas the abandoned area (under natural restoration) had less than half that amount (51 t ha^{-1}) (Table 1). This is probably because woody plants in the natural restoration area were not included.

3.1.2. Fire behaviour

The results in Table 2 indicate that the rate of fire spread in the corn farm (5.61 m min^{-1}) was higher than in the mixed deciduous forest (4.68 m min^{-1}). The speed with which the fire spread in the abandoned area and in the 5-year swidden farm, however, was relatively low. In the abandoned area, fuel moisture content was high, while heavy fuel (slashed logs) was observed in the swidden farm, resulting in a lower rate of spread (ROS) in the area. It was found that the fire intensity in the 5-year swidden farm was highest, followed by the abandoned area. The average flame length was also the highest in the swidden farm, reaching about 12 m, while the flame length in the corn farm reached only about 1.5 m. A higher fire intensity in the swidden farm could be explained by a higher fuel load, high temperature, high wind speed, and lower relative humidity during the duration of the prescribed fire experiment. The fuel distribution was also a factor contributing to a higher rate of fire spread, intensity, and flame length.

According to the fire intensity scale developed by Andrews (1980), the scale of fire intensity in this study was medium. In contrast, when applying the forest fire rating scale developed by Akaakara (1996), the fire intensity in the corn farm and mixed deciduous forest in Nan province was more than 301.03 kW m^{-1} and was classified as high (danger). Fire intensities calculated in this study were also compared with other studies in similar ecosystems. Wanthongchai, Tarusadamrongdet, Chinnawong, and Sooksawat (2013) reported that the fire intensity in a degraded pine forest of Nam Nao National Park, Petchabun province, was 626.60 kW m^{-1}, which is higher than that reported in this study. This could be because the degraded pine forest had more fuel load, mainly composed of grass and leaves (45.40% and 44.35%, respectively). In contrast, Junpen, Garivait, Bonnet, and Pongpullponsak (2013) found a fire intensity of 166.30 kW m^{-1} in a deciduous forest of Doi Suthep-Pui National Park, which was lower than that reported in this study, despite the fact that the fuel load reported by Junpen et al. (2013) was similar to that of the mixed deciduous forest reported in this study (3.88 t ha^{-1}). This may be due to lower relative humidity and high wind speed in the present study, which helps with the combustion of fuel and increased fire intensities. Moreover, Junpen et al. (2013) did not mention the slope of the sampled terrain, as it can highly influence the fire intensity. The present study was in an area located on a very steep slope (>35% gradient) and this resulted in a high rate of fire spread and hence higher fire intensity.

3.2. Highland fire risk maps

The fire risk maps of Thailand, Northern Thailand, Myanmar, and Lao PDR are shown in Figure 1.

Study site	Land use	Fire temperature (°C)		Fuel consumption (%)	Fire behaviour		
		Maximum	Average		Rate of fire spread (m min^{-1})	Fire intensity (kW m^{-1})	Flame length (m)
Nan province	Corn farm	629	544.9	93	5.61	562.06	1.42
	Upland rice farm	NA	NA	NA	NA	NA	NA
	1-yr swidden farm*	NA	NA	NA	NA	NA	NA
	5-yr swidden farm*	756	447.4	87	1.12	3202.5	12.82
	Abandoned highland	708	349.5	47	1.26	893.2	7.13
	Mixed deciduous forest	799	743.77	91	4.68	463.83	1.34

Remarks: * indicates no burning. NA implies not applicable.

TABLE 2. Fire temperature and behaviour descriptors in the highland areas of Thailand.

These were produced using a newly available online beta tool provided by FAO OpenForis, called EarthMap (https://earthmap.org/). Even though the software is in its beta phase, the results look promising with high quality and rich data sources from lead agencies such as NASA and European Space Agency (ESA). The risk map is also dynamic, with maps modified based on additional high-quality information obtained from MODIS satellite products. Such fire risk maps can help to determine human activities to a higher degree of accuracy as burnt patches detected by satellites indicate where humans usually use fires. Information about the burnt area is better than details about active fires (hotspot) as a hotspot is just a point located in the middle of a pixel and does not tell how big a particular fire is. Moreover, such information can be uploaded and a user with an internet connection can access the maps and focus on a specific area of interest to explain the practice in more detail if needed.

EarthMap (version 1.0.0) is a tool to analyze past environment and climate based on the Google Earth Engine and developed in collaboration with the Government of Germany through The International Climate Initiative (IKI) of the Federal Ministry of the Environment Nature Conservation and Nuclear Safety. New risk maps are shown in Figure 2. The carbon maps from fire emissions during the months from January to April for 2018, 2019, and 2020, in the upper ASEAN region, are shown in Figure 3.

3.3. Understanding the meteorology and air pollutant emission from fire in the study domain through climatology, measurements, modelling, and climate change scenarios

This study focused on two constituents that can make aerosols and result in unhealthy levels of surface particulate matter (PM). These are the mixing layer (ML) height and the levels of PM (PM10 and PM2.5) emissions from the surface. We focused on the months of February, March and April of 2018, which are the months during which PM2.5 surface emissions increased and were at a maximum in Chiang Mai, northern Thailand. As seen in Figure 4, the monthly mean and median diurnal (daily) variations (blue and green lines) in ML height differ significantly between February (Figure 4A), March (Figure 4B), and April (Figure 4C).

In February (Figure 4A), the ML height gradually increases from 00 local time and reaches the first peak at around 08 local time. After that, the ML height decreases and reaches a minimum value around noon. The ML height increases again and stays at a maximum value until 18 local time. It then gradually decreases during the night. Since the ML height acts like a cover inhibiting the dispersion of air pollutants, higher ML heights usually result in a lower surface PM, and vice versa, during the dry season. This can also be observed during the month of April (Figure 4C). However, during March (Figure 4B), the diurnal variation amplitude in ML height is significantly smaller. We hypothesize that this may be due to aerosol-meteorology interactions.

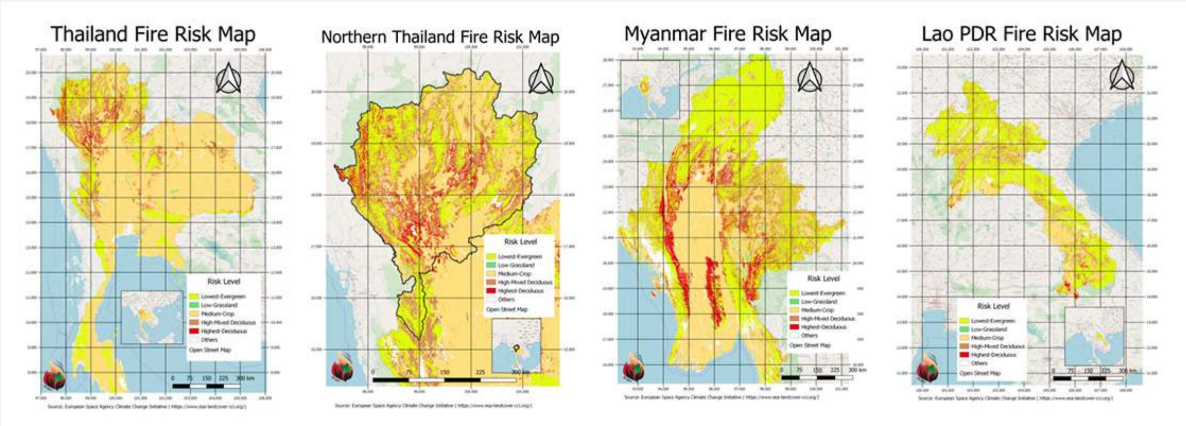

FIGURE 1. Constructed fire risk maps of Thailand, Northern Thailand, Myanmar, and Lao PDR (Source: European Space Agency Climate Change Initiative, https://climate.esa.int/en/).

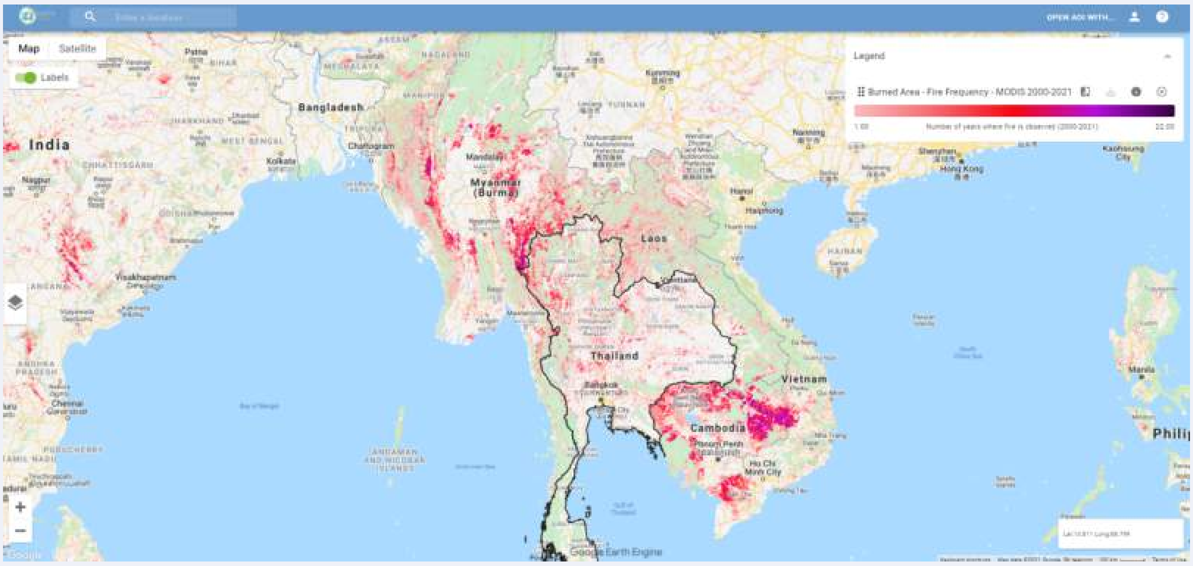

FIGURE 2. Upper ASEAN Risk Map by overlaying 22 years of burned areas as determined through MODIS (Source: https://earthmap.org/and https://lpdaac.usgs.gov/products/mcd64a1v006/).

3.3.1. Meteorology effects on aerosol or particulate matter concentrations

If surface particulate matter emissions reach an exceptionally high level, it may also affect the local meteorology. In particular, it may affect the diurnal variation of ML height, such as that observed during March 2018. This hypothesis was tested during the PLUME experiment as part of the 2019 7-SEAS project deployment during March 2019 in Fang District, Chiang Mai, northern Thailand, close to the border with Myanmar, where extensive particulate matter emissions were observed during this period. In theory, if there is a significant level of aerosols (particularly absorbing aerosols such as black carbon) emitted from the surface to the atmosphere, this will increase the ambient PM concentration in the air (Tao et al., 2020). If the aerosols are absorbed naturally, it will warm up the atmosphere near the top of the ML and cool the surface due to a dimming effect caused by the absorption of the aerosols. A cool surface and a warm top ML induce a temperature inversion that may suppress the development of the ML height and trap the air pollutants near the surface. This was observed in our LiDAR experiment and is depicted in Figure 5.

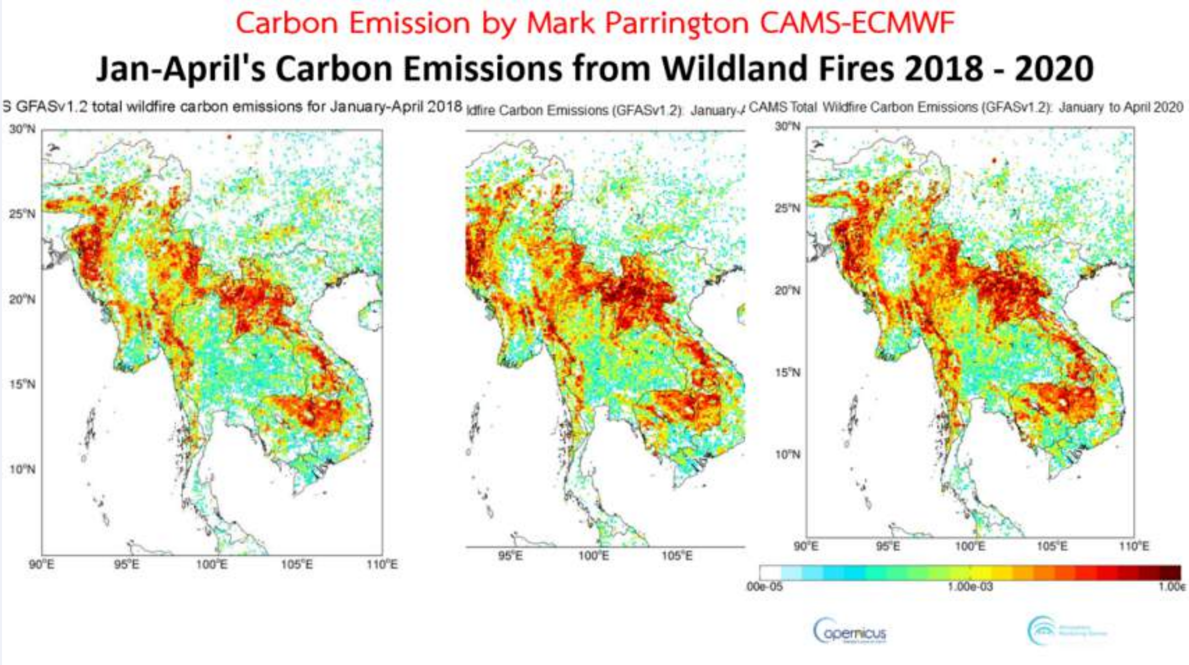

FIGURE 3. Combined maps of carbon emissions in the upper ASEAN region during January-April from wildland fires of years 2018 (left panel), 2019 (middle panel), and 2020 (right panel) (Source: Mark Parrington, GFAS-CAMS-ECMWF).

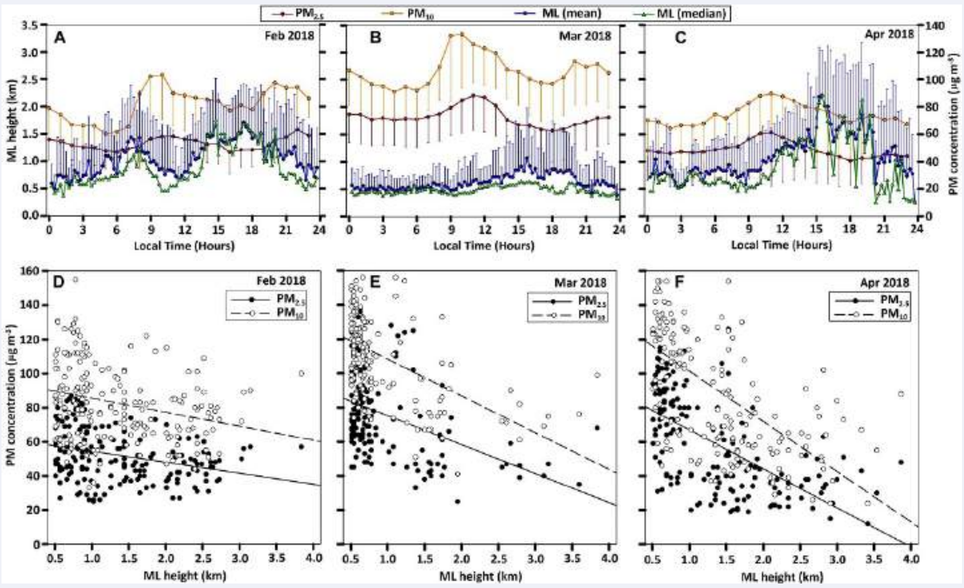

FIGURE 4. The effect of variability in mixing layer height (ML) on the surface PM2.5 concentrations (Solanki et al., 2019).

3.4. Encouraging people participation in fire and smoke management using concepts of Integrated Forest Fire Management (IFFM)

3.4.1. Agricultural activities and forest resource utilization by humans causing forest fires

The growth of agro-industry has led to a reduction in forest area through burning to expand farmlands. Farmers use fire for land preparation as it is an easy and low-cost approach. Several communities, particularly in the upper northern Thailand, use fire for farm management and integrate it into their livelihoods and traditions.

Hin Lad Nai Community is a Karen community located in the Huay Hin Lad Nai valley of the Khun Chae National Park, at an elevation of 900 m above sea level (masl) in the Wiang Pa Pao District,

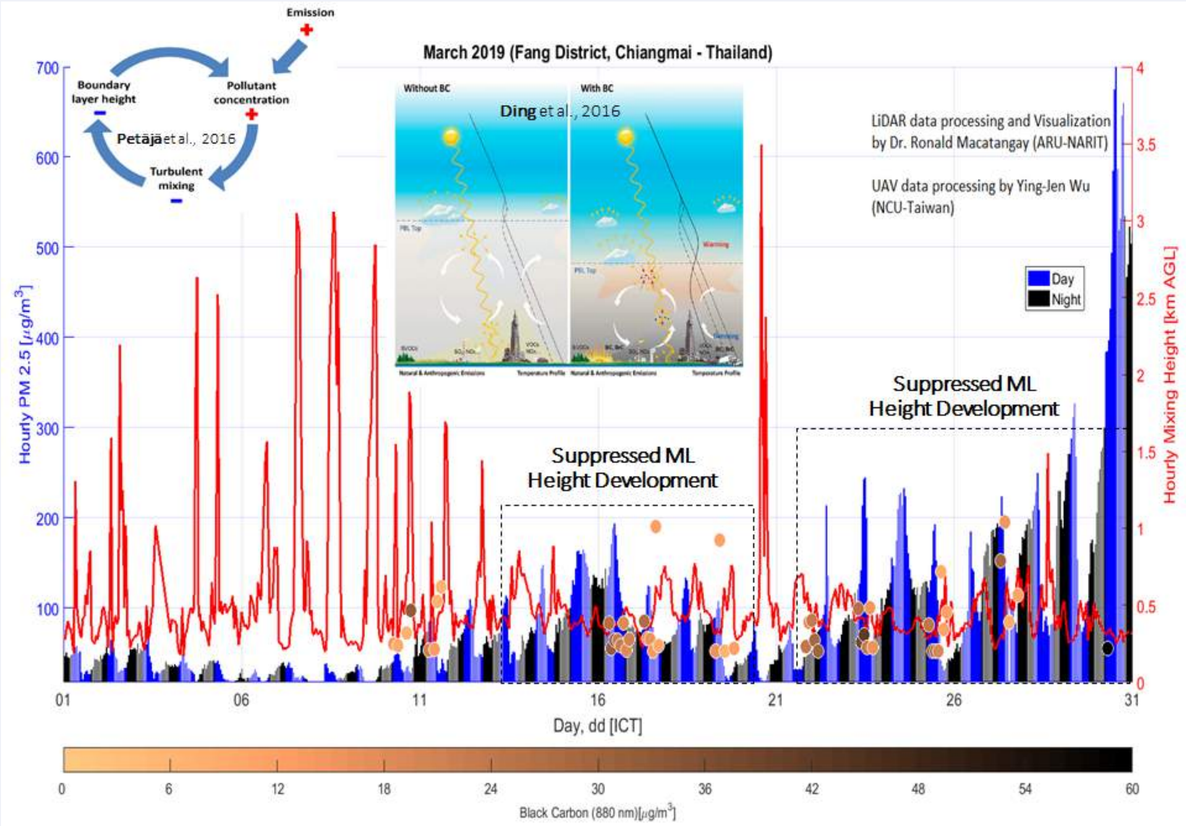

FIGURE 5. Suppressed mixing layer (ML) height development (red line; right axis) due to a significant amount of PM2.5 (black and blue bars; left axis) and maximum black carbon (brown dots; colour bars) concentration and altitude (right axis). Source: Climate Change Data Center-Chiang Mai University 2019, National Central University-Taiwan 2019, Petäjä et al. (2016) and Ding et al. (2013) .

Chiang Rai Province. The community has unique approaches to manage land use and forest fire, which are different from other communities. The community uses a combination of land-use and forest area zonation as agreed among its community members to manage the forest area and its resources. These approaches have led to sustainable farming, an efficient management of forest fires and reduction in selling of land to outsiders or changing land ownership, which one cannot sell to other, but can be transferred within the family members. To manage forest fires and prevent haze pollution, the community adopted IFFM through the participation of community members, youth, government authorities, researchers, and civil society organizations; and by applying a combination of traditional knowledge and local wisdom with new technologies and innovation to develop a CBFiM plan. The community established a board to debate on policies and make decisions on any activities related to utilizing forest area and its resources. For example, if a community member would want to cut trees in the forest to build a house, they would need permission from the community board. For agriculture, the community uses rotational farming. Farmers divide planting plots into 7 sub-plots and only use one plot per year, leaving the rest for natural recovery. The farmers would use the same plot or a smaller area for farming each season without expanding the planting area into the forest. All the plots are recorded in a database and mapped to prove that the agricultural area has not expanded over time. This practice is different from the usual shifting cultivation in other regions practicing highland agriculture.

Through the partnership, participatory process and concrete CBFiM action plan, the community developed ownership, acceptance and cooperation, which allows for sustainable agriculture practices while conserving natural resources and preventing forest fire. Moreover, the community established a community fund to manage forest fires, which benefits from selling forest products such as bamboo shoots and honey. The community agreed to allocate 0.25 THB per kilogram of sold bamboo shoots and 20 THB per bottle or kilogram from selling honey to the community fund. The fund was used to buy equipment for the construction of firebreaks, covering the cost for fire patrols during January and April every year, and buying food for the members who are involved with the fire management activities.

Key strengths of the Hin Lad Nai community that have contributed to the success of forest fire are community knowledge, local wisdom and traditions, which teach the people to love and conserve the natural resources. The knowledge includes sustainable agriculture, knowledge about indigenous vegetation, importance of biodiversity and ancient traditions, which have been passed on from generation to generation. In addition, the community is open to learning and adopting new technologies and knowledge. For example, the community adopted a mobile application to monitor forest fire in the community and the surrounding area. The community also developed a database of the natural resources using Geographic Information Systems and developed a map to classify the forest types, land use types, firebreak locations and eco-tourism areas. The community actively participates in training and capacity development activities organized by the government and civil society organizations. Therefore, the community became a part of the knowledge and experience exchange network, which enabled them to receive news and remain up-to -date on the current situations.

4. CONCLUSION

In the highlands, local people still practice burning of residue after harvesting, and the fuel loads on the higher side, and with a steep slope, the fire intensity is high. Fire risk maps of Thailand, northern Thailand, Myanmar, and Lao PDR can help us classify the high-risk areas to be used as references while determining the areas with potential fire risk. We focused on the annual haze events that occur over the upper highlands of Indochina. We used a mini micro-pulse LiDAR system to complement the existing surface air pollution monitoring systems. We also quantified the diurnal variability of the ML height over the Chiang Mai valley from April 2017–March 2018. The maximum ML heights during April, May and June reached altitudes of up to 3 km during July, August and September; 2 km during October, November and December; and 1.5 km during January and February. During March, the ML height was generally at its lowest, at around 500 m from the ground. The role of the ML height in the variations of air pollutant concentrations over the Chiang Mai valley was significantly evident during the dry season. High ML heights produced lower air pollutant concentrations near the surface, and lower ML heights produced higher air pollutant concentrations near the surface. During March, when there were significant emissions of absorbing aerosols, we observed that the development of ML height was suppressed, causing air pollutant accumulation near the surface due to an aerosol-meteorology feedback mechanism.

The success of forest fire management in the Hin Lad Nai Community was due to an integration of strong traditional knowledge about the conservation of natural resources and farming practices, and new technology and knowledge to manage forest fires. Key factors contributing to the community participation included: 1) benefit from participation; 2) channels and opportunities to participate; 3) opportunity to be involved in defining the objectives and scopes of work; 4) community leaders; 5) support from the government and other parties; and 6) integration of human rights, livelihoods and traditional aspects. Furthermore, participation in knowledge exchange platforms enhanced the understanding further and led to a successful and sustainable IFFM.

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APN Secretariat
East Building, 4F
1-5-2 Wakinohama Kaigan Dori
Chuo-ku, Kobe 651-0073 JAPAN

Tel: +81 78 230 8017
Fax: +81 78 230 8018
Email: info@apn-gcr.org
Website: www.apn-gcr.org