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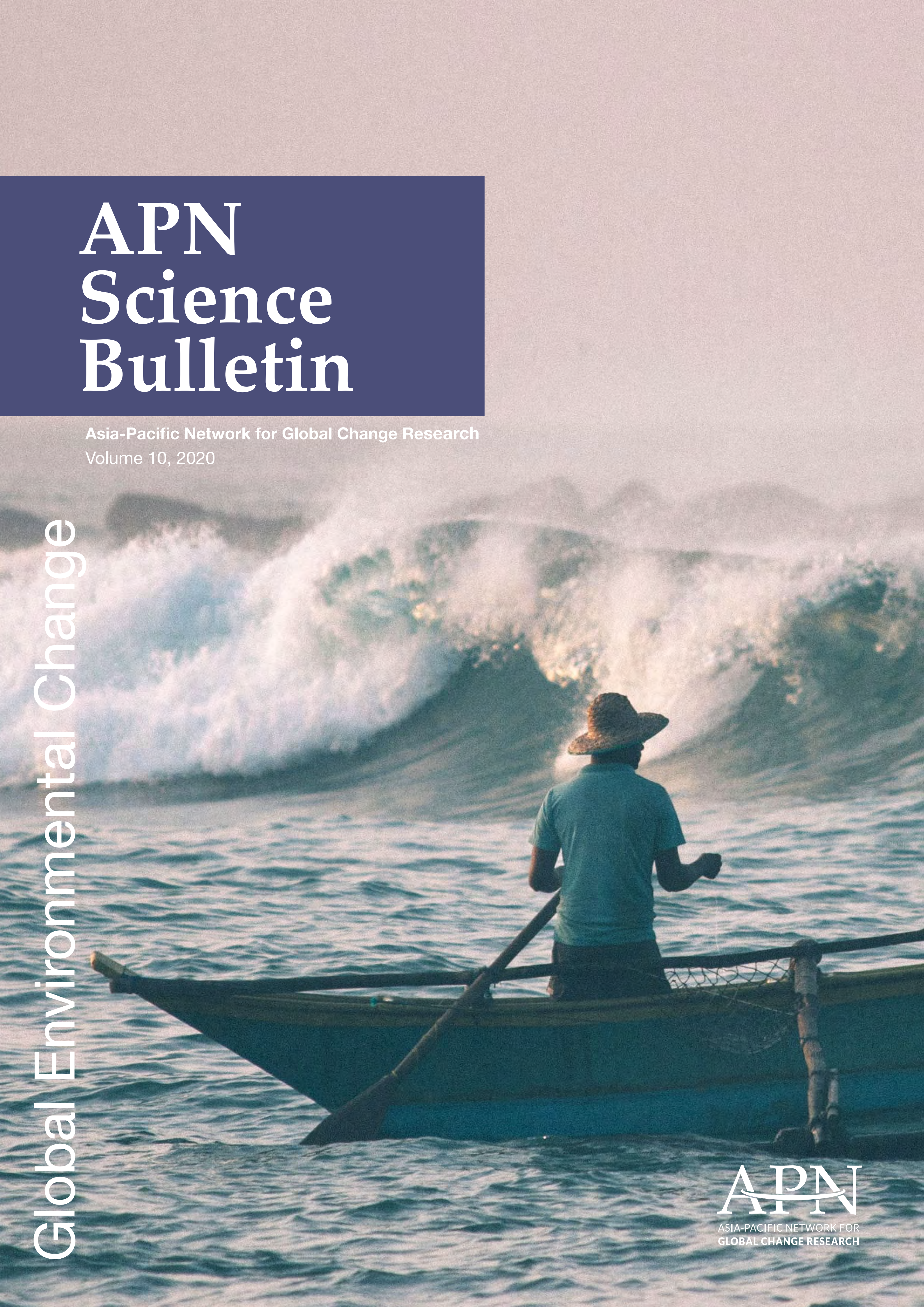

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The APN Science Bulletin is a peer-reviewed digital publication that features research and capacity building projects funded by APN. The Science Bulletin is intended for readers from both science and policy-making communities, as well as young scientists 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

2020 has been a tough year with the COVID-19 pandemic and many of our projects faced challenges in completing their projects according to their original timelines. But this did not impact their dedicated work and contribution to APN's Science Bulletin with more determination than ever. This year we published a record 17 articles in our Science Bulletin and this compilation is available in the present Bulletin and in our publication's library in the new APN website https://www.apn-gcr.org/bulletin/.

As the articles become available, we continuously check the statistics and, with thanks to the tireless efforts of our authors, reviewers, and editorial team, I am delighted to let you know that, at the time of publishing this compilation, we have had at least 9,000 views on the Science Bulletin site over the calendar year 2020. There has been a total number of 565 PDF downloads of articles published in the 2020 Science Bulletin, which is our 10th Edition. As we become more established as a peer-review source of scientific literature in the world of global environmental change, our articles have been cited by 74 research papers, according to CrossRef.

The 17 articles featured in our 2020 Science Bulletin are regionally balanced articles published from our Comprehensive Research Programme (CRRP), our Climate Adaptation Framework (CAF) and our Capacity Development Programme (CAPaBLE). The articles cover a broad range of issues, including methodologies to assess loss and damage caused by the impacts of climate change, lessons learnt from implementing training on ecosystems resilience and integrating health into urban planning towards sustainability.

As we enter a new strategic phase from February 2021 and approach our 25th anniversary of the establishment of APN, we remain committed to providing a robust, peer-reviewed scientific resource that continues to be a go-to place for a knowledge product that is easily and openly accessible to all, free of charge.

On behalf of the Science Bulletin management team and our Scientific Planning Group Co-Chairs, I would like to extend a heartfelt thank you to our authors and our 2020 Editorial Board (refer to inside cover), for your contributions to the 10th Edition. It has been an honour and pleasure working with all of you, particularly given the challenges we have faced this year. Here is to our continued partnership, stronger than ever.

Stay safe and well.

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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Improving women's access to climate information services and enhancing their capability to manage climate risks

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ABSTRACT

Climate information services has been demonstrated as a potential tool in supporting farmers to manage climate risks. However, the existing gap or disconnect between institutions that develop climate information and farmers who are the primary users of climate information can be addressed by building their capacity in an integrated manner by covering all the associated actors from production to use. This study primarily addressed the capacity building processes focussing on women's uptake of climate information at the users' level and value addition process of climate information into agro-advisories at the institutional level, to reduce the risk in agricultural production systems. The pathways for improving uptake and use of climate information to help decision-making by women farmers are: delivering information and agro-advisories relevant to their needs, having trained local level communicators, and group approach and support to act on the information. This paper demonstrates how capacity building of associated stakeholders in the whole climate information chain can address the barriers and improve the use and uptake of such information by women farmers, supporting their changing role in farming.

KEYWORDS

Adaptation, Capacity building, Climate change, Climate risk managers, India, Tamil Nadu, Women

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HIGHLIGHTS

- Trained women communicators enhance the uptake of climate information for women.
- Meeting women's climate information needs is the best pathway to enable information use.
- Group approach adds value to the demand for climate information.
- Collectives play a role in facilitating women's capabilities to act on climate information.
- Building capacities of associated stakeholders enables the use of climate information.

1. INTRODUCTION

1.1 Context

1.1.1 Climate risks

Climate variability and climate change are the most critical threats today in sustaining agricultural production, food safety, food quality and livelihoods of people depending on agriculture and retaining farmers' interest to take part actively in agriculture and make innovations (Howden et al., 2007; Gezie, 2019). In India, the most important climate change dimension relevant to farmers is increased frequency and severity of extreme events such as seasonal droughts, floods and cyclones (Food and Agriculture Organization of the United Nations [FAO], 2001; Mall, Singh, Gupta, Srinivasan, & Rathore, 2006). Farmers in rainfed regions, especially smallholders, are highly vulnerable to these variations (Sathyan, Funk, Aenis, & Breuer, 2018).

The intensity of climate change seems to be complex and has vast implications in agriculture and farmers' livelihoods. A study by the Ministry of Environment and Forest (MoEF), Government of India (GoI), has pointed out that extreme temperatures are anticipated to rise by 1°C to 4°C with a maximum rise in coastal regions; while extreme precipitation events will increase by 5 to 10 days in all four regions (The Himalayan, The Western Ghats, North-East and Coastal regions) with a decrease in frequency of cyclones and increase in their intensity by 2030 (MoEF, 2010). Another study by Kumar et al., 2011 over India showed that there would be an overall increase in temperature by 1°C to 4°C and summer monsoon precipitation by 9% to 16% by 2080 compared to the baseline 1970s, yet, on smaller regional scale some regions experience lower rainfall than the baseline period.

Such changes negatively impact the livelihoods of smallholders by affecting their production, income and employment. Based on the literature, the Economic Survey of India (2017–2018) study at the all India level reported that extreme temperatures and droughts have adverse impacts on farm incomes, especially in unirrigated agroecologies. It further stated that the year in which temperatures increase by one degree Celsius, farmer incomes would drop by 6.2% during the *Kharif* [1] season and 6% during Rabi [2] in unirrigated districts across India (GoI, 2018). Likewise, in a year when rainfall is 100 mm less than average, income would reduce by 15% during *Kharif* and by 7% during the *Rabi* season (GoI, 2018).

A study by International Labour Organization (ILO) warns that "the loss in productivity by 2030 because of heat stress could be the equivalent to India losing 34 million full-time jobs (up from 15 million in 1995), the highest among the world's most populous nations" (ILO, 2019, page 12). Also, there is some likelihood that the quality of the agricultural product (micronutrients-proteins) decreases under increased CO_2 fertilization. Crops grown under elevated CO_2 concentrations are more susceptible to insect pests. Weeds, insects and diseases are likely to increase in a warmer climate, and this will potentially reduce crop yields and lead to a decrease in agricultural productivity. Global warming may enhance bio-accumulation of fungal toxins (mycotoxins- aflatoxins, fusarium toxins) in crops like wheat and maize, posing a significant threat to food security. Achieving food security under a changing climate requires enhancing capacities of farmers to cope with the risks posed by climate change which can be achieved through climate change adaptation and mitigation measures (Kibria, Haroon, & Nugegoda, 2013).

While in the state of Tamil Nadu, located in the southern part of the country, the impact of climate change is expected to be more in 2050 than in 2020. The average yield reductions will range from 3.5% in paddy to 13.4% in sugarcane by 2020 and will be 4.5% and 9.4% in 2050, respectively. In the Tamil Nadu State Action Plan for Climate Change, it is indicated "The PRECIS A1B scenario predicted that there is likely to be a decrease in rainfall in 2070s by about 1% to 9% concerning the baseline rainfall (1970–2000). The maximum temperature is also likely to increase by about 3.1°C" (Government of Tamil Nadu [GoTN], 2015, page 98). Detailed analysis has shown that although there was no deviation in the annual rainfall and number of rainy days in Cauvery delta during the period 1970–2000, the river basins that fall south of the Cauvery river basin recorded a reduction in annual rainfall by 9.8% with a profound decrease in annual rainy days by 32.3% (Jain & Kumar, 2012). Another study by Guhathakurta, Sreejith, and Menon (2011) between 1905 and 2005 shows that the number of dry days in the state has exceeded wet days in a year.

The main climate risks in Tamil Nadu affecting agriculture are increasing the occurrence of extreme events, mainly seasonal drought in consecutive years, which reduce the farmers' adaptive capacity and negatively impact their livelihood. Further, intra-seasonal distribution of rainfall, quantity and number of days, play an important role in agricultural production. Another vital aspect is cyclone impacts, which affect the production systems to a larger extent by damaging assets and infrastructure (GoTN, 2015).

1.1.2 Changing role of women in agriculture

These impacts of climate change and environmental shocks are particularly significant given the changing nature of women's engagement in agriculture. Women are more vulnerable to adverse climate impacts due to their marginalization, inequality, poverty and limited access to productive resources like knowledge, information, technology and institutional linkages (Carr & Thompson, 2014). Women in the least developed countries and developing countries in Asia and Africa are responsible for food production (agriculture, livestock, fisheries, aquaculture), the collection of water and biofuel (wood), management of natural resources and taking care of children and elderly. Women farmer accounts for 45-80% of all food production in poor developing countries (UN Women Watch, 2009). Climate change is projected to cause a severe impact on rural women via crop failure, food and water contamination, shortages of biofuel and clean water, diseases and natural disasters, etc. (Kibria, 2016). The Economic Survey of India (2017–2018) cites the increasing trend of feminization of agriculture sector with the increasing role of women as cultivators, labourers and entrepreneurs (GoI, 2018). The changing trend is mainly due to growing rural-urban migration by men, an increase of women-headed households and an increase in the production of commercial crops which are labour intensive (FAO, 2019). Also, men are moving out to non-farm livelihoods, and as a result, women are increasingly involved in newer roles in agriculture, decision making and overall farm management. However, they have limited access to productive resources, including social and information and communication networks as compared to their men counterparts.

1.1.3 Climate information services

The climate information and advisory services are one of the potential ways to support farmers' to adapt to climate change (Carr, Goble, Rosko, Vaughan, & Hansen, 2017; Tall, Coulibaly, & Diop, 2018; and Singh et al., 2018). The improvements in climate forecast modelling have increased the accuracy of the forecast information at different spatial and temporal scales. Evidence has shown the positive results of forecasts in agricultural production by reducing risks in crop cultivation and allied sectors (Patt, Suarez, & Gwata, 2005; Meinke et al., 2006). In India, currently, the Indian Meteorological Department (IMD) provides operational level Medium Range Weather Forecast (MRF) and Extended Range Forecast (ERF) at district and state spatial scale respectively. Based on the forecast, agro-advisories are developed by identified nodal organizations (Agro Meteorological Field Units) and disseminated to the farmers through several extension methods. In addition, IMD has recently initiated block-level MRF (reducing the spatial scale with increased efficiency) and advisories and district level ERF.

However, smallholders, especially women farmers, do not have timely access to climate information and capacity to translate forecasts into suitable crop advisories. Also, while developing the agro-advisories, gender-differentiated needs are not considered by the nodal organizations, and thus advisories are generally based on the major crops cultivated in the district, which is mainly food and commercial crops. Recently the World Meteorological Organization (WMO) initiated a discussion and reiterated the need for addressing the gender dimension in climate services concerning agriculture and food security, water management, etc. It also recommended increasing investment in climate services (production, dissemination and capacity building to use) to reduce the gender gap (WMO, 2015).

1.2 Research questions

Against this backdrop, the paper deals with the process undertaken to engender climate information services and facilitating its access and utilization by smallholder women farmers. An action research study

FIGURE 1. Agro-ecological zone in Tamil Nadu.

was undertaken from 2018–2019 in Tamil Nadu, India, to explore two research questions: (1) How to build the scientific capacity and leadership of women farmers in the uptake of climate information? Moreover, how can it be sustained at the community level? (2) How can the use of climate information to women farmers be enhanced?

2.METHODOLOGY

The study took place in the south zone of the Tamil Nadu, which is one of the seven agro-ecological zones in Tamil Nadu state (Figure 1) and consists of six districts (sub-unit). The zone has seven Agro Meteorological Field Units (AFMUs). The AMFUs is the nodal point at the zone level, and they receive weather forecasts and develop and disseminate agro-advisories.

Capacity development activities targeted four different sets of stakeholders who play a critical role in ensuring the appropriate climate information reaches farmers (Figure 2). The stakeholders were categorized into two levels: organizational level and grassroots level; at the organizational level, the first two sets of stakeholders (2.1 and 2.2) were involved, and the remaining two (2.3 and 2.4) were at the grassroots level. The number of members trained is given in Table 1.

The approach adopted in this intervention was in line with suggestion of Ambani and Percy (2014) in Africa, in which they have reiterated the need for capacity building of all stakeholders involved in the process of climate

Category of the programme	*Level of interaction*	*Type of stakeholders in the climate/weather information chain*	*Total number of participants*	*Main purpose of the programme*
Organizational level	State	Agromet Field Unit (AMFU) facilitators	7 (7 M / 0 F)	Adopting a gendered approach in advisory development
	South Zone of Tamil Nadu	Farmers association[3] (FPO/ federations/interest groups)	21	Raising awareness and linkages to facilitate climate information services to farmers
Grassroots level		Climate Risk Managers (CRM)	30 Female	Building knowledge and skills on climate risks and adaptation measures especially climate information services
		Farmers	3,000 Female	Awareness to access and use weather/ climate information
Policy level	State	Academicians, civil society leaders, policymakers and researchers	14 (8 M/6 F)	Sharing field evidence, results and opportunities

TABLE 1. Details of participation in capacity building programmes. Note: The further information relating to farmers association and CRMs are included in annexures 1 and 2, respectively, in the supplementary material.

information at production, communication and adoption to realize its potential use in risk reduction.

The general objective of the initiative is to build the awareness, knowledge and skills, which varies among different stakeholders as outlined in Table 1. A series of workshops and a consultation were organized with various stakeholders as elaborated in Table 1. Before the initial workshops, a baseline assessment was done with all stakeholder categories to capture their level of knowledge, issues and use, respectively. At the end of the programmes, the assessment was repeated to understand the level of changes in their capacity to carry forward the weather/climate information services in a concerted manner in reaching women farmers.

At the AMFU facilitator level, the main focus was gender sensitization, while in the FPO/group level it was on awareness building on the use of climate information as well as to establish linkages with institutions to receive the climate information and advisories. At the next level with climate risk managers (CRMs), importance was given to build the knowledge and skills on climate risks and adaptation measures as well as communication with farmers and at the farmers level, it was on where to receive and use it for risk management. Finally, a consultation was held with relevant officials and researchers to share the learnings and results of the whole process.

2.1 Training the facilitators of Agro Meteorological Field Unit

At the first level, the facilitators of the AFMUs, who act as nodal points to receive the forecast and develop agro-advisories, were oriented on gender issues and preparing agro-advisories taking into consideration the differential needs of the diverse farmer's group in the field level. Participatory tools and processes were adopted to sensitize the facilitators on gender issues and to follow a gendered approach when preparing advisories. For example, when selecting crops/livestock for providing advisories, priority needs to be given to those crops in which women have a lead role, such as millet crops and floriculture, agronomic practices like weeding and harvesting which are typically assigned to women in the division of labour on different tasks and small ruminants and poultry which are primarily managed by women at the farm household.

2.2 Training members of Farmer's Association (a network of small farmers)

Twenty-one farmers' associations were identified for training. The main selection criteria were field presence of more than five years and between 500 to 1,000 members. The selected Farmer Producer Organizations (FPOs) were oriented on project objectives, activities, methods, expected outcomes and expected policy inputs. Following this, a consultative discussion was organized with selected farmer groups and the potential of climate information and agro-advisories in strengthening farmers' resilience, role of farmers' groups in the whole process and identifying innovative women farmers at the field level who could mediate the process of knowledge transfer at the local level to farmers, were explained.

2.3 Building capacity of climate risk managers

With the support of the farmers' associations, thirty community level intermediaries (women) were selected from 30 villages and trained to be CRMs to extend climate information services to local farmers regularly. The selection parameters for the CRMs were:

lead farmers in adopting new technologies, innovators in refining technology to suit the local context, readiness to share the experiences and process with other farmers, already playing the role of leader in such processes, have minimum basic education and good mobilization and organization skills to discuss issues closely with farmers.

A simple training module was developed to train the CRMs on different aspects related to climate and weather forecasts, agro-advisories, institutions providing forecast and advisory details and contact details to access the information such as emails and phone numbers, assessment and understanding of local cropping systems/patterns, local agro-climatology, specialised training to understand the traditional knowledge about climate predictions from men and women farmers to initiate the dialogue and communicate with them, and potential adaptation practices using the climate information, etc. Then, seven training modules were developed to build the knowledge, skills and ability of CRMs to communicate climate information. The module covered the themes namely:

» weather and climate;
» what is climate change and factors triggering the change;
» impacts of climate change;
» addressing the challenges—both adaptation and mitigation methods;
» what is climate information;
» types of climate information;
» who is generating the forecast and advisory development; and
» simple thumb rules for adding value to weather information as advisories and communication of the information to the farmers.

Four capacity building programmes were organized face-to-face. The first meeting was arranged with all the CRMs gathered together, and the remaining three were conducted in their respective locations.

2.4 Raising awareness and training women farmers on using climate information

Each of the CRMs facilitated village level training of 100 women farmers in their respective locations by participating in farmer group meetings and screening videos to motivate discussion amongst them. The process of interaction was participatory and structured to get feedback from farmers on their traditional prediction and coping measures. Three thousand women farmers were trained using climate information through this approach. Also, efforts were taken to provide the agro-advisories through text SMS/voice SMS. In this process, 3,000 women farmers from 30 villages were trained and are receiving regular weather advisories.

2.5 Policy advocacy interactions

Policy level interaction was organized with the support of climate centre of Anna University in Chennai, and a roundtable discussion was conducted with officials from the Department of Environment and Forests, Government of Tamil Nadu, the nodal point for the development and implementation of the State Action Plan on Climate Change. The field-level experiences were presented in the meeting and discussed. As part of the dissemination process, a policy brief was prepared and shared with them. Discussions are ongoing to incorporate the recommendations in the state action plan on climate change. Also, there is scope to share the climate information services in the UNFCCC dialogues and discourses with the support of eminent researchers and officials engaged in policy-making processes.

3. RESULTS AND DISCUSSION

3.1 Relevance of building the capacity of different actors in the climate information chain

The capacity building initiatives adopted a whole chain approach in creating access and promoting utilization of climate information and suitable adaptation practices in the respective locations. As discussed, four different sets of actors were oriented on gender-sensitive climate information services (Table 1). Also, 3,000 women farmers are now linked with AMFUs to receive climate information and agro-advisories, continuously. Such knitted training and a comprehensive intervention at multiple levels help to increase the uptake of climate information. It was observed that in the initial phase, the women were not taking any decisions; they shared details with their family members. Before the training programme, though women had observed the changes in the weather pattern, they were not confident enough to comprehend and articulate their understanding. Their confidence increased following training, which is in line with evidence that a lack of awareness and capacity to access and use climate information is the main reason for the slow uptake in decision-making (Opitz-stapleton, 2010).

3.2 Making relevance for climate information

The experience shows that providing simple needs-based climate information improved the uptake by women farmers. Here, focus was given to build the capacity of the AMFU facilitators to (i) add value to their climate and weather forecasts that have relevance to women's actual needs; (ii) develop simple contents on how to address the issues with the sources to get more details and technical support, (iii) study the traditional knowledge in prediction and farmers practice in referring the intensity of the weather variables to enable the communication process; (iv) disseminate through women's groups and FPOs to reach more women farmers; and (v) use innovative communication modes like voice mails and social-based media such as WhatsApp audio messages to reach women with limited literacy skills.

The WMO has been advocating the need to provide clear and user-targeted information on weather and climate through its national focal points. In addition, it gives importance to improve the awareness of farmers and other user groups on the value of climate information in decision-making (WMO, 2007). A study by Kniveton et al. (2015) in Kenya and Senegal also clearly indicated the importance of producing user need-based information and advisories for practice.

3.3 Profile and role of trained women communicators and group approach to improving the uptake of climate information for women

Creating a cadre of intermediaries at the community level helps to improve the nodal points in the social network in seeking climate information. While identifying CRMs, care was taken to select CRMs who (i) lead in adopting new technologies, (ii) have a quest for and positive attitude towards continuous learning (iii) are willing to share experiences and processes with other farmers, (v) already play the role of leader in such processes, (vi) have basic education and can read and write; and (vii) have good mobilization and organization skills to discuss issues closely with farmers. The intensive and series of the capacity building programmes prepared the CRMs to communicate the climate information to the farmers effectively. It was evident from the pre- and post-capacity building assessments that their technical knowledge, skills, leadership capabilities, institutional linkages and social networks were improved.

Thus, using simple rules of thumb and understanding crop-weather relations, the CRMs were better equipped to develop and disseminate local and needs-based agro-advisories for weather and climate forecasts. Despite the increased awareness, women farmers' uptake of climate information is limited; however, the group approach helps to remove the barrier and enables women to share and demand climate information. In the farmer group meetings, participants shared their experiences in listing advisories, agronomic practices adopted in their field and changes, difficulty in understanding advisories, and additional information provided by FPO facilitators and others. Such discussions helped them to learn from each other and develop trust in the information. This is in line with findings from the recent research of Rengalakshmi, Manjula, and Devaraj (2018) in the study area that highlighted the results of women communicators in enhancing the use of climate information and its dissemination among women.

3.4 Sustaining the demand for climate information

Creating awareness among women on the availability of climate information services, supporting them in getting connected to services through a mobile network, strengthening their capacity to seek information and facilitating information-sharing mechanism in groups are some of the potential strategies to equip them to act on the information. The continuous interaction of CRMs with women in sharing the forecast and agro-advisories support women farmers to observe, develop trust and translate them the information into action. The CRMs are from the local village, and bi-weekly they share the weather forecast-based advisories suitable to the local farming system. Apart from this, they act as a link to avail other services of the FPOs. The CRMs deliver the agro-advisories by bundling with other services. For example, if the forecast advisory is for sowing maize/cotton, then they provide information about the availability of quality seeds, its price and potential yield and performance. This bundling approach supports women farmers to come forward and use climate information services. However, limited resource control and lack of opportunity to participate in agricultural decision-making can significantly restrict women's capacity to make full use of climate information. Integration of these climate services along with other agricultural services like access to quality seeds of required crops and varieties, capacity building on technologies and institutional linkages can facilitate higher uptake of the information (Muema, Mburu, Coulibaly, & Mutune, 2018).

4. CONCLUSION

Capacity-building programmes at multiple levels in the whole information chain seem to be a potential strategy in tackling gender-based issues that impact differing access to climate information to smallholders, especially women farmers whose role and direct contribution in agriculture is growing. In spite of the extension network to disseminate the climate information services, establishing a grassroots level cadre of women communicators is a best-practice strategy in improving the uptake of climate information as an adaptation measure. The new knowledge and learning on climate information and advisories paved the way for women farmers to understand the science behind actions and will enable them to take knowledge-based decision making for better farming in the context of increasing climate variability and change and lead to climate-smart agriculture. Sharing and showcasing the chain approach in capacity building with policymakers supported the provision of evidence and scientific input to policy decision-making processes, and was another positive outcome. The study attempted to ensure the sustainability of the initiatives through working with institutions at the state and grassroots level to improve the use and uptake of climate information in reducing climate risks.

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ENDNOTES

[1] Based on the monsoon pattern in India, the main cropping seasons are divided into *Kharif* and *Rabi*: Kharif prevails between June and October coinciding with South-West Monsoon.

[2] Rabi season starts in October and ends in February March in North-East Monsoon season.

[3] See supplementary material.

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Challenges and opportunities to approach zero waste for municipal solid waste management in Ho Chi Minh City

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ABSTRACT

Ho Chi Minh City (HCMC) is a mega city with a total population of more than ten million. The quantity of solid waste generated has been increasing significantly over the past two decades, and the average generated solid waste was 1,164 tonnes/day in 1992 and 8,845 tonnes/day in 2017. Municipal solid waste (MSW) management has been considered as one of the most severe environmental problems as the quantity of solid waste has increased while infrastructure for collection and treatment is not sufficient. The paper focuses on evaluating challenges and suggesting opportunities for reducing the amount of waste disposal in landfills through interception and separation of the waste at source. After the waste separation, the biodegradable organic materials and recyclable materials from MSW can be collected for further use. Based on the current situation of MSW management, technologies such as composting, biogas recovery and electricity generation either from anaerobic digestion plants or sanitary landfills are appropriate. Incineration for high calorific value waste can be adopted for energy recovery. Effective recycling technologies to convert waste into valuable products seem to be a solution for approaching zero waste for MSW management in HCMC.

KEYWORDS

Biogas, Composting, Landfill, Municipal solid waste, Solid waste separation at source, Zero waste

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HIGHLIGHTS

- » Lack of infrastructure and appropriate source segregation are major issues.
- » Waste composition from households/markets indicates more than 60% biodegradable organic fraction.
- » Waste segregation plays a vital role in solid waste management.
- » Composting and anaerobic digestion seem to be feasible for biodegradable organic fraction.
- » Value materials recovery and incineration for high heating value waste can be adopted.

1. INTRODUCTION

Ho Chi Minh City (HCMC) is a mega city with a total area of 2,095 km^2. HCMC has 24 districts, 19 urban and 5 rural. The total population is more than 10 million, with a growth rate of 10.2% (Nguyen, 2013). According to the social report of HCMC in 2016, the average gross domestic product (GDP) per capita was 5,700 USD (HCM People's Committee, 2016). The accelerated economic growth and rapid urbanization have resulted in serious municipal solid waste (MSW) management problems.

The quantity of solid waste generated has been increasing significantly from 1992 to 2017 (Figure 1). In 2017, the total waste generated was about 8,845 tonnes/day (Department of Natural Resource and Management-Ho Chi Minh City [DONRE], 2009). From 2010 to 2017, the solid waste growth rate was about 6–8% per year, with an average solid waste generation of about 1.07 kg/capita/day (DONRE, 2016). In addition, segregation at source is not widely practised. Therefore, MSW management has been considered as one of the most severe environmental problems as the quantity of waste has increased while infrastructure for collection and

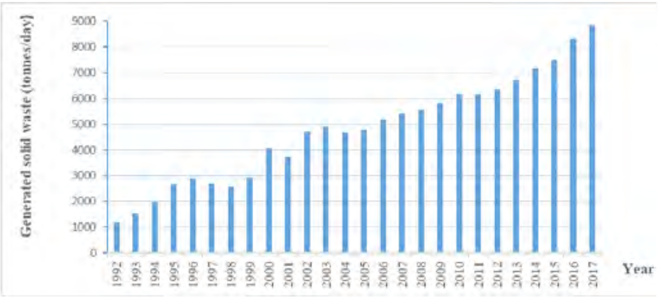

FIGURE 1. Solid waste generation in HCMC from 1992 to 2017.

treatment is not sufficient. The Government of HCMC has given priority to the problem and is interested in promoting effective and appropriate technology in solid waste management. The objective of this research is to propose sustainable resource utilization techniques in the rapidly urbanizing city. Challenges and opportunities to address this issue are discussed in the paper.

2. METHODOLOGY

2.1 Baseline data collection

Collection of baseline data was undertaken between October 2014 and June 2015. Both primary and secondary data were collected from relevant sources. Data includes characteristics of waste, generation rate, options for waste management, and disposal technology, including any reuse/recycling practices adopted.

2.2 Solid waste management option identification

Challenges and opportunities were identified in order to draw management options. These options were based on the current situation, composition, government policies, facilities, technical skills, and financial resources.

3. RESULTS AND DISCUSSION

3.1 Current situation of municipal solid waste management in Ho Chi Minh City

The current solid waste management system of HCMC is shown in Figure 2. MSW is collected and transported directly or via transfer stations to sanitary landfills or composting plants. Recyclable waste is separated during the collection process at the source (households, offices, schools, and business units) by residents and informal collectors.

According to DONRE (2016), the collection rate of MSW in HCMC achieved 100% in inner city areas and 95% in suburban areas. At present about 68.6% of collected solid waste is disposed of in sanitary landfills, 24.5% of collected solid waste is disposed of in compost plants, and 5.7% in incinerators.

3.1.1 Generation and storage

Generation sources of MSW are residential areas with 2 million households, 346 business units, 354,661 units of hotels/motels, 12,502 medical units, 4,730 offices, education and training organizations, and about 12,000 industrial factories and enterprises. Households generate 57.9% of MSW (DONRE, 2011).

At present, no separation of MSW takes place at the source. However, most households separate valuable waste such as cans, plastic, paper, etc., from their waste and sell to waste buyers. In general, the critical points related are the high amount of commingled solid waste generated, no standard containers for storage, limited space in households for placing containers, high amount of leachate and malodour generation, and lack of public awareness.

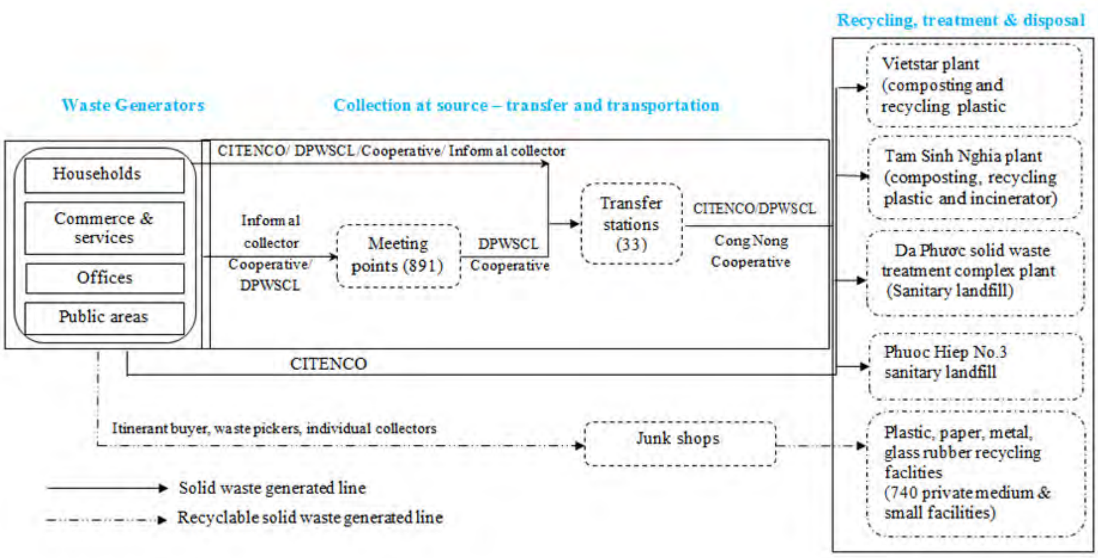

FIGURE 2. Current solid waste management system in HCMC.

Composition	**Results (%ww)**									
	Households			Schools		Market		Sanitary landfill		Composting plant
	2009[a]	**2015**[c]	**2017**[c]	**2009**[a]	**2015**[c]	**2009**[a]	**2015**[c]	**2012**[c]	**2014**[b]	**2015**[c]
Biodegradable fraction	74.3	64.8	59.2	28.7	25.5	86.8	87.8	68.9	67.9	53.2
Wood, straw	2.8	0.9	2.4	6.9	-	3.6	1.4	0.7	0.3	1.0
Paper	6.2	5.1	6.4	17.6	35.0	2.5	1.9	3.0	2.5	5.7
Plastic	5.2	10.5	10.9	25.9	34.9	4.3	7.5	16.0	16.4	12.9
Textile	1.0	3.2	4.0	1.1	1.0	0.4	-	5.0	7.2	10.7
Leather	0.2	-	0.6	0.1	-	-	-	-	-	-
Rubber	0.9	0.9	2,0	1.4	-	0.4	-	0.7	0.7	0.7
Glass	1.3	1.4	2.6	0.5	1.2	0.2	-	1.2	0.2	1.7
Nonferrous metal	0.7	0.6	2.7	2.1	-	-	-	1.6	3.6	0.3
Ferrous metal	0.3	0.2	2.8	0.7	-	0.3	0.1	-	-	-
Porcelain	0.8	0.5	2.8	0.6	-	0.1	-	-	-	2.4
Soil, sand	3.2	2.8	-	4.0	-	1.0	1.2	-	-	-
Ash	0.4	-	-	-	-	-	-	-	-	-
Styrofoam	0.3	1.0	3.0	9.8	1.5	0.4	0.2	-	-	0.8
Diaper	1.8	8.1	0.6	-	-	-	-	2.3	0.6	10.7
Clamshell	0.8	-	-	-	-	0.2	-	0.8	0.6	-
Hazardous waste	0.002	-	-	0.1	-	0.1	-	-	-	0.1

TABLE 1. Composition of municipal solid waste generated in HCMC from 2009–2017. Note: "-" none in this composition; ww – wet weight. Sources: DONRE (2009) (a), HCM Climate Change Bureau (2014) (b) and CENTEMA (2012-2017) (c)

3.1.2 Solid waste collection and transportation

Collection, transfer and transportation of solid waste in HCMC are carried out by two systems: public and private systems. The public system consists of HCMC City Urban Environment Company Limited (CITENCO) and 22 District Public Work Service Company Limited (DPWSCLs). The private system consists of informal collectors and cooperatives. Collectors in the private system collect 60% of solid waste while those from the public system collects the remaining 40%.

One major problem is that collection equipment is not standardized. This is especially true for equipment used by informal collectors. Other problems include narrow transport pathways in dense areas; non-standardized collection facilities and lack of safety facilities; lack of collection skills and the practice of separating recyclable waste, which causes delays in collection time and generates pollution; lack of monitoring and control; and non-integrated management.

HCMC has 33 transfer stations with a total design capacity of 5,477 tonnes/day. According to the annual report of DONRE (2014), 100% of waste generated was collected, transferred and transported. However, waste transfer and transportation is complex and inadequate for the following reasons: (1) there are many companies involved in this activity and who work independently from each other making it difficult to organize and integrate the transport activities and routes; (2) inadequate infrastructure, such as narrow and poorly paved routes, non-standardized collection cars/trucks, lack of meeting points and insufficient transfer stations; (3) lack of tools, guidelines, regulations to support the waste transport system; (4) poor management capacity; and (5) insufficient funding.

3.2 Waste characteristics

The survey results from 2009 and 2017 show that different sources have different waste characteristics (Center for Environmental Technology and Management [CENTEMA], 2009; CENTEMA, 2017). Most of the fraction is biodegradable organic fraction. Recyclable fraction varies depending on the source, as shown in Table 1. In addition, household hazardous wastes (HHW) are also present in MSW.

3.3 Solid waste reuse and recycling

Based on the characteristics, composting and recycling of valuable materials are adopted in the study.

3.3.1 Composting

At present, there are three composting plants: (1) Vietstar with a capacity of 1,200 tonnes MSW/day; (2) Tam Sinh Nghia with a capacity of 1,000 tonnes MSW/day; and (3) Vietnam Waste Solution (VWS) Company with a capacity of 1,000 tonnes MSW/day. If three composting plants were to run at full capacity, 100% of the biodegradable organic fraction of generated MSW would be treated to produce compost. However, VWS Company is not operating because solid waste is not separated at source. The input of two composting plants is commingled waste and therefore, the separation process has to take place after transport, which is complex, costly and requires a lot of labour. An abundant component in MSW is plastic, which needs to be removed before the waste is composted. At Vietstar and Tam Sinh Nghia plants plastics are separated, cleaned and processed into plastic pellets, which contribute to the income of the plant.

At the Vietstar and Tam Sinh Nghia plants, aerated static pile composting (windrow composting) technology is used. Currently, the capacity of the Vietstar plant is 1,200 tonnes/day, in which 773 tonnes of solid waste are for composting, 7 tonnes of solid waste is recyclable plastic, and 420 tonnes are non-recyclable materials for disposal at the Phuoc Hiep No.3 sanitary landfill. The capacity of the Tam Sinh Nghia plant is 1,000 tonnes/day, in which 350 tonnes/day is for composting, 50 tonnes/day for recycling plastic, and 600 tonnes/day for incineration (DONRE, 2015). As mentioned, the input of all composting plants is commingled waste; thus the compost product contains amounts of hazardous household waste, glass and plastic, which results in a decrease in the quality of compost making it very difficult for market sale. For this reason, poor quality compost is used for levelling sulphate contaminated areas to improve the landscape and soil quality.

3.3.2 Recycling

The amount of recyclable waste collected is about 1,400 to 1,800 tonnes per day (Nguyen, 2015). The recyclable waste such as plastic, paper, glass, and metal are collected at several stages of the collection chain at households, at meeting points, during transport and at composting plants. After separating the recyclable from households, the waste is sold to waste buyers first, and then to junk shops followed by selling to large junk shops or recycling facilities. Most of this recyclable waste is processed by local recycling facilities and some recyclable waste, such as plastic and metal, are exported to China (Nguyen, 2015). Additionally, recyclable waste is sent from other cities and provinces in the vicinity for processing. HCMC has about 1,100–1,200 junk shops and 740 recycling facilities that recycle about 2,000 tonnes of recyclable waste per day. This system also creates jobs for 16,000–18,000 unskilled labourers.

3.4 Solid waste disposal

The ratio of MSW disposed at sanitary landfills accounts for about 68% of total solid waste collected. This is higher than the target in the HCMC 5-year plan (2010-2015), which is 40%. At present, two sanitary landfills are in operation. First, Da Phuoc solid waste treatment complex, owned by California Waste Solution Company, operates at a capacity of 5,000 tonnes/day (increasing from 3,000 to 5,000 tonnes/day in 2015). Most of the solid waste generated in HCMC is transported to Da Phuoc sanitary landfill for disposal. Second, Tay Bac Cu Chi solid waste treatment complex owned and managed by CITENCO, operates at a capacity of 2,000 tonnes/day. This landfill receives the remaining solid waste from the Vietstar plant. Both landfill sites are designed as sanitary landfills.

However, inhabitants have filed complaints regarding odours and the quality of effluent discharged from treatment systems as they do not meet effluent standards of Vietnam.

3.5 Challenges and opportunities for sustainable solid waste management

3.5.1 Challenges

Major challenges in the current MSW management system are presented in Figure 3. Due to low public awareness, waste segregation is a major challenge. As such, most of the MSW is currently not separated at source. Further, the absence of refuse bins for specific waste type (e.g. recyclable waste and organic waste) also hinders waste segregation. During waste collection by the informal sector, both recyclable and organic waste

FIGURE 3. Challenges in solid waste management practices in HCMC.

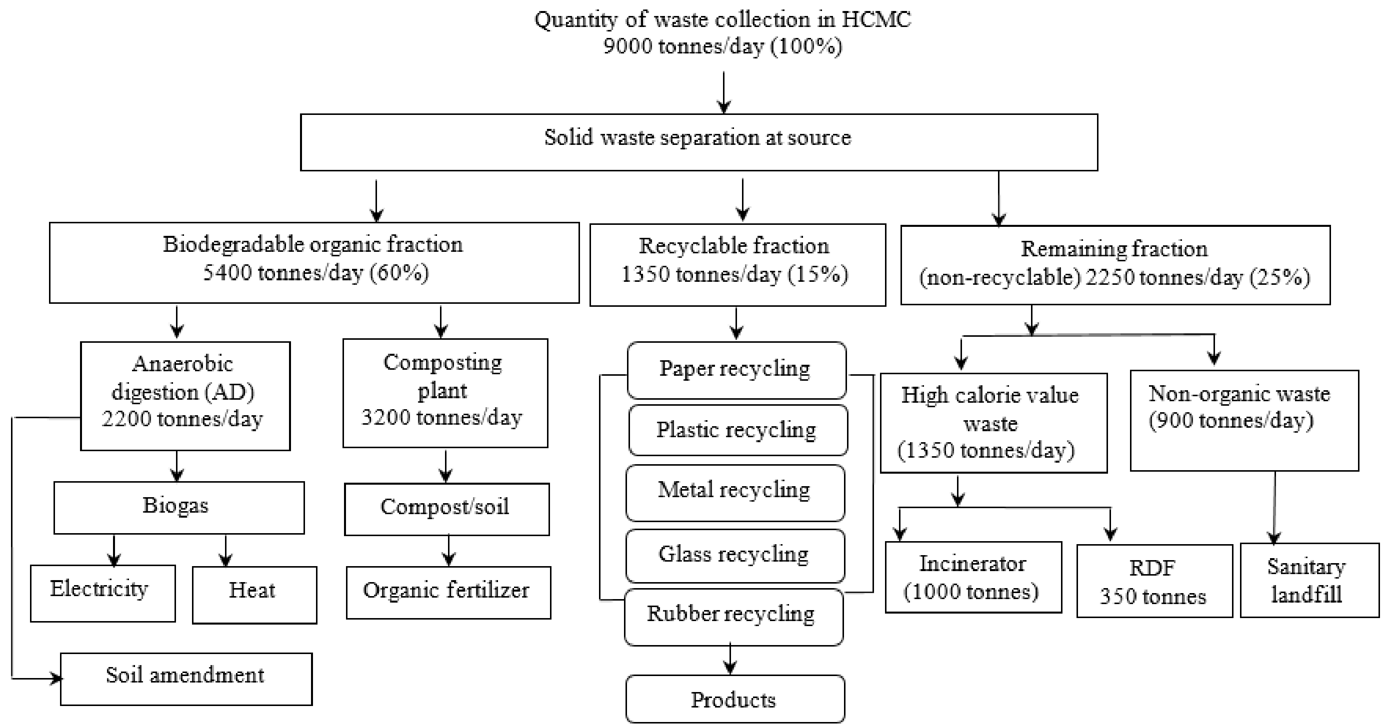

FIGURE 4. A proposed solution for a zero waste management system in HCMC. Note: remaining fraction includes non-recyclable waste (high calorie value solid waste: diapers, rubber, and Styrofoam) and non-organic solid waste (porcelain, clamshell, ash, soil, sand).

are dumped together into containers, which discourages people from segregating the waste.

Limited availability of technology is a major challenge in implementing solid waste management, and solid waste treatment technologies currently used are sanitary landfills (68.6%), compost production (24.6%) and incinerators (5.7%).

Financial constraints and a lack of human resources also present a major challenge in implementing solid waste management. The amount of revenue collected from the services provided by the municipality is less than the amount invested for collection, transportation and disposal of solid waste. Therefore, the current form of solid waste management is unsustainable in the long term.

3.5.2 Opportunities

The results from this study on MSW management in HCMC from 2009 to 2017 show that many opportunities exist for sustainable MSW management and are listed below:

» Biodegradable organic fraction is approximately 65% in domestic solid waste and, if it is well separated at source, it can be used as a raw material for compost or fermentation processing instead of disposing at the landfill.

» The potential agricultural demand for organic fertilizers and soil conditioners is very high and exceeds actual production capacity. High biodegradable organic fraction (64.8-74.3%), composting technology and anaerobic digestion technology with collection of biogas, is the most sustainable technology for the utilization of solid waste. Non-recyclable waste with high calorific value is suitable for incineration or refuse-derived fuel (RDF) technologies with an energy recovery system.

» The network for recycling activities is very large, including 740 private facilities recycling about 15-20% of MSW collected. Recyclable components including paper, plastic, and metal, can be recycled to create new products.

» In order to obtain pure biodegradable organic and remain fractions, solid waste separation at source (SWSAS) plays an important role in integrated solid waste management. Separating MSW at source can be applied at various levels through media campaigns and educational programmes. In Viet Nam, there are many social organizations such as Women's Union, Young Communist League, Veterans' Union, and HCM young pioneer organization. These social organizations can play a leading role in the implementation of SWSAS programs.

» Viet Nam has a policy to increase the use of green energy. The unit price for electricity produced from biogas is 7USD/kW and from incineration is 12 USD/kW. This policy can encourage the use of waste treatment technologies such as anaerobic digestion technology with biogas collection and incineration technology with energy collection.

» HCMC has established policies to support SWSAS programs, encouraging investment on technologies for recycling solid waste with energy recovery.

3.6 Set targets for MSW in HCMC from 2016 to 2025

According to the decision No. 491/QD-TTg dated 7 May 2018 on the adjustment of National strategy on integrated solid waste management for 2025 and vision for 2050, the Government of HCMC has developed a program to minimize environmental pollution for HCMC every 5 years. The targets of solid waste management in the period 2010-2015 were: sanitary landfill 40%, composting 40%, recycling 10%, and incineration 10%. However, these targets have not been achieved as they are too high when compared to infrastructure conditions, level of available technology, and human resources in HCMC. In June 2017, HCMC People's Committee promulgated a Resolution on "Urban environmental protection and waste management in the HCMC" with targets of solid waste management to 2020. Following the Regulation, sanitary landfill technology will reduce to 60% and other technologies will increase to 40% including recycling of waste (paper, plastic, metal, glass, construction waste), incinerator, and biodegradable waste to produce compost and biogas. In 2025, sanitary landfill technology is expected to be 25%, with other technologies increasing to 75%.

According to the quantity and composition of generated solid waste and set targets for MSW in HCMC for 2025, the proposed solution for zero waste management is presented in Figure 4.

4. CONCLUSIONS AND RECOMMENDATIONS

A proposed solution for a zero waste management system in HCMC for sustainable resource utilization is drawn based on the current situation, composition, national policies, and targets for MSW management. It can be adopted for reducing the amount of waste entering into landfill. The solutions are in line with the government policies and take into consideration socio-politic, environmental and economic aspects.

Based on the proposed solution, the majority of waste can be intercepted and converted to energy and compost. Recyclable fractions can be collected after effective source separation and this will benefit the participating community. Other incentive schemes such as shared-income, tax reduction or award systems, can be developed to ensure the sustainability of the project.

However, the proposed solution will be successful when government policies are directed towards sustainable waste management. The Government of HCMC should promulgate policies that will encourage recycling activities. Financial support should be provided to the recycling sector to improve existing recycling facilities or for investment in new facilities with advanced technologies. In terms of technologies, incineration, anaerobic digestion, and RDF are suitable options for MSW management in HCMC. The government should (1) promote a clear and simple investment regime; and (2) develop infrastructure that will merge energy generated from MSW into the national grid.

One of the main aspects to achieve waste management leading to zero waste is separation at source. For HCMC, the SWSAS program is proposed and factors that will ensure successful implementation of the program are as follows:

» Increase the participation of authorities at all levels (city, district and ward) as well as social organizations.

» Ensure strong leadership for the implementation of SWAS.

» Issue legal documents to serve the SWSAS program that includes: (1) regulation on classification and storage at source; (2) collection at source and from streets; (3) transit and transport; (4) reuse and recycling; (5) policies; and (6) participation of social organizations.

» Establish a regulation on management of informal MSW collection sector, handling of waste by this sector, and punishment for violation. Effective management of informal collectors will contribute significantly to SWSAS program implementation.

» Capacity building programs for human resources involved in solid waste management should be developed and implemented. Strengthening capacity of staff at all levels, especially at community levels, can be of great value.

In addition, the public can play an important role in effective MSW management. They can play an important role in separating waste at source, waste reduction, and recycling, which are essential to achieve a zero waste management goal. In order to replicate the implementation of the project in other localities, lessons learnt from the implementation of the program in HCMC should be analysed and factors affecting successful implementation should be identified and adapted to local conditions.

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Sustainable mangrove rehabilitation: Lessons and insights from community-based management in the Philippines and Myanmar

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HIGHLIGHTS

- Science-based approach in coastal rehabilitation is being promoted to solve worsening coastal environmental problems.
- Community-based forest management approach encourages participation, strong collaboration and commitment of local communities in collaboration with research institutions, government and non-government institutions.
- Science-based rehabilitation guidelines should be communicated well to local communities.
- Key facilitating factors for successful mangrove rehabilitation are clear policies, secured rights, and good governance.

ABSTRACT

This study generally aims to synthesize the best practices and challenges in mangrove rehabilitation in the Philippines, Myanmar, Japan, China and India. It employed an in-depth review of secondary information such as policy documents and project reports, and participatory research activities with various mangrove stakeholders such as key informant interview and focus group discussion. Lessons and strategies obtained were used to develop a mangrove rehabilitation framework or guideline. The guideline was tested for suitability through case studies in the Philippines and Myanmar. It was concluded that mangrove rehabilitation will succeed if 1) it is built around an integrated and ecosystem-based approach that takes into account feedback between rehabilitation and other economic activities; 2) its scope is beyond mere planting; 3) local people are involved in planning and monitoring in addition to implementation; 4) all stakeholders are informed of their roles and responsibilities; and 5) species selection is based on ecological and silvicultural knowledge in conjunction with the needs and priorities identified by stakeholders.

1. INTRODUCTION

Mangroves provide a range of ecosystem services. These largely include the provision of timber, fuel wood, medicines, natural dyes, honey, and marine food. They also help in regulating floods, erosion and saltwater intrusion; and protect coastal communities against the harsh impacts of storms and tsunamis. Further, there are several aesthetic and cultural services that mangroves provide, including those related to tourism, education, and local indigenous knowledge and traditions. Mangroves are confined largely to the tropics and sub-tropics. Among the continents, Asia has the most extensive mangrove forest cover, but with the most serious deforestation rates (Food and Agricultural Organization of the United Nations [FAO], 2015). Mangroves, particularly in Southeast Asia, are globally distinguished for their high biodiversity (Tomlinson, 1986; Giesen & Wulffraat, 1998). Mangrove cover has been reduced from 6,025,000 ha in 2010 to 5,329,000 ha in 2015 (FAO, 2015). Many mangrove stands are on the brink of complete collapse after being converted to

FIGURE 1. Location map of study areas in Asia. Source: ArcGIS Online.

aquaculture ponds, agricultural farms, oil palm and settlement areas (Kathiresan & Bingham, 2001; Gevaña, Pulhin, & Tapia, 2019). Low awareness of ecological and economic values of mangroves also led to their neglect in national forest conservation and biodiversity protection plans (Snedaker, 1984).

Over the past two decades, mangrove conservation and rehabilitation have gained interests with the increasing recognition of their role to minimize the impacts of tsunami and storm surge (Garcia, Malabrigo & Gevaña, 2014; Gevaña, Camacho, & Pulhin, 2018). Further, mangrove plantation development was also driven by the increasing demand for fuelwood, poles, charcoal and woodchips, and more importantly, because of their ecological ecosystem functions (Aksornkoae & Kato, 2011). However, numerous planting efforts implemented were unsuccessful due to the lack of science-based approach guidelines (Primavera and Esteban (2008); López-Portillo et al., 2017).

Given the challenges in mangrove conservation, a collaborative research study was undertaken to synthesize the best practices and challenges in mangrove rehabilitation in the Philippines, Myanmar, Japan, China and India. Further, this study endeavoured to develop mangrove rehabilitation frameworks/guidelines by distilling the best practices and lessons learned from the secondary information, participatory assessment of the outcomes of rehabilitation treatments in field in selected areas and collaboration of multi-country team of researchers, as supported by the Asia Pacific Network for Global Change Research (APN).

2. METHODOLOGY

To achieve the study objectives, participatory research methods were undertaken. These included:

» review of secondary data (e.g. policy documents, project reports and scientific publications) in terms of the different elements of rehabilitation treatments; ecological, economic and social costs and benefits; challenges and opportunities; and implementation arrangements described covering all mangrove areas in the Philippines, Myanmar, Japan, China and India (Figure 1); and

» key informant interviews (KII) with various mangrove stakeholders (e.g. government agencies, non-government organizations, and local community organizations).

Results of the review and participatory research activities were synthesized to develop a mangrove rehabilitation framework, or guidelines. To check the guideline suitability, case analyses were undertaken in three communities in the Philippines, and one in Myanmar. This involved the conduct of focus group discussions with selected local community members implementing mangrove rehabilitation projects.

2.1 Study sites

The study covered mangrove rehabilitation efforts in the Philippines; Myanmar, Japan, China and India (Figure 1). The Philippines has estimated mangrove forests of about 356,000 ha, with a recent decadal deforestation rate of 0.5% (Gevaña, Camacho, & Pulhin, 2018). In Myanmar, mangroves span 502,911 ha. In India, Sundarbans are well-known as one of the most extensive contiguous mangrove forests in the world. India has 4,921 sq. km of mangroves, contributing 3.2% of the global estimate. Five provinces viz., Guangdong Province, Guangxi Autonomous Region, Hainan Province, Fujian Province and Zhejiang Province cover 57.3%, 25.5%, 13.7%, 3.4% and 0.1% of the total mangrove area (17,800 ha) of China, respectively. In Japan, mangroves are found chiefly in the southernmost prefectures of Kagoshima and Okinawa, with its northern limit located in Kiore. They cover about 553 ha.

2.2 Study components and methods

The study aimed to identify mangrove rehabilitation practices, challenges, and lessons learned among the collaborating countries. In summary, the research team accomplished the following activities:

- A literature review of past reports on mangrove rehabilitation (from the year 2000 onwards) and state-of-the-art knowledge of mangrove ecology was examined.
- A list of criteria summarizing the success and challenges of rehabilitation was developed, namely: 1) site; 2) duration and budget; 3) planting design (including species composition); 4) survival rate; 5) stakeholder participation; 6) provision of socio-economic benefits; and 7) success and constraining factors.
- In-depth on-site case studies in the Philippines and Myanmar describing suitability of the proposed guidelines/comprehensive framework through key informant interviews (KII) and focus group discussions (FGDs).
- Policy consultations with relevant government, non-government, academic and research institutions were held through KII and FDGs. These were aimed at eliciting: 1) key mangrove rehabilitation policies and programmes and their congruence with sustainability; 2) effectiveness of policy implementation; 3) perceived issues and challenges in policy implementation; and 4) recommendations to improve policies.

3. RESULTS AND DISCUSSION

3.1 Mangrove rehabilitation best practices, challenges and lessons learned

The literature review supplemented by field observations in selected locations suggested that empowerment of local communities by legitimizing their resource

Country	*Reasons for mangrove losses*	*Best practices*	*Issues and challenges*	*Lessons learned*
Philippines	• Conversion to aquaculture ponds, rice paddies and reclamation for settlement and industrial development • Typhoons/storms	• Adoption of community-based forest management (Executive Order No. 263, 1995) that has spurred collective efforts to rehabilitate other degraded coastal environments	• Poor survival in plantations due to wrong choice of species for planting • The CBFM participants in mangrove areas cannot avail the incentives compared with the CBFM participants in the upland areas such as security of tenure and exemption from forest charges for harvesting	• Need for harmonised mangrove policies and institutions to help promote effective sustainable management and rehabilitation • Science-based process is a prerequisite for rehabilitation
Myanmar	• Extraction of fuelwood/timber • Mangrove conversion into shrimp ponds, settlements and rice paddies • Large scale fish and prawn farming	• Adoption of mangrove-based agroforestry practices, community-based mangrove management and ecological mangrove restoration	• Limited studies that assess the causes of degradation and insufficient communication of results • Policy gaps on requiring feasibility assessment, monitoring and enforcement through multi-disciplinary approaches	• Need for integrated approach to mangrove rehabilitation, including: – knowledge-based planting methods, – social mobilization, – livelihood support – policies on reaching planting
India	• Conversion to urban zones and shrimp farms • Overharvesting • Storms and urban pollution	• Legal and regulatory institutions were set up for the protection of mangroves • Integration of apiculture with rehabilitation for local income	• Inadequate labour resources, lack of facilities, and inappropriate use of financial resources • Both plantations and natural forests in deltaic regions suffer massive losses due to erosion	• Need for long term-participatory-adaptive restoration programmes
China	• Conversion to agriculture/aquaculture • Reclamation for urban development • Overfishing and introduction of invasive species	• Selective cutting and gap planting of Sonneratia apetala in secondary forests • Ecological aquaculture combining mangrove rehabilitation with shrimp farming	• Reforestation on bare beaches and integration with human-made fish reefs are very costly to implement • Survival rate of mangrove seedlings remains quite low	• Strengthen protection of mangrove nature reserves, rehabilitation of degraded mangroves, and provide more support for research and rehabilitation work
Japan	• Cutting for firewood, construction material, dyeing and antiseptic agents • Reclamation for urban and industrial areas	•No aquaculture farms in mangroves area • Cutting and destroying mangroves are strictly restricted • Tourism is a more beneficial industry than aquaculture	• Land-based problems such as red-soil runoff due to unsustainable agriculture practices and garbage pollution	• Mangroves are well-conserved in Japan for their ecological, educational and touristic values

TABLE 1. Best practices, challenges and lessons learned regarding mangrove rehabilitation from participating countries.

FIGURE 2. Participatory Mangrove Rehabilitation Framework.

use rights as well as management responsibilities was the key factor driving successful mangrove restoration in the Philippines and Myanmar. Furthermore, local income from non-timber forest products (in India), ecotourism (in Japan), and shrimp farming (in China) are guaranteed if healthy mangrove forests are well-kept. In all countries, the feedbacks between mangrove restoration, other land uses and non-land economic activities were considered crucial for conserving biodiversity, mitigating climate change, increasing resilience to climate change, and sustainable socioeconomic development. Poor survival rates of planted mangroves were observed to be the result of: 1) poor planning; 2) limited understanding of the site's ecology; 3) poor programme management/governance/policy concerns; 4) tenure insecurity; 5) occurrence of natural disasters; 6) poor monitoring; and (7) lack of timely corrective measures (Table 1).

3.2 Guidelines and comprehensive framework for sustainable mangrove rehabilitation

Using the information from lessons learned on past and current efforts in mangrove rehabilitation (Table 1), a comprehensive framework for pursuing sustainable community-based mangrove rehabilitation was developed. This framework emphasizes that rehabilitation is not merely a process of planting of trees, but a holistic effort to address broader environmental, economic and social imperatives across spatial and temporal scales (Pulhin, Gevaña, & Pulhin, 2017). It involves several steps, as also reflected in the mangrove rehabilitation manual developed by Primavera et al. (2012) (Figure 2).

3.2.a Local site coordination.

Forest rehabilitation should be properly coordinated with relevant stakeholders. Ensuring transparent, just and sound stakeholder engagement is at the heart of all successful rehabilitation projects. Rehabilitation must rest on a shared vision and all stakeholders should have a clear understanding of their roles, responsibilities and benefits. This sets the foundation for ensuring accountability.

3.2.b Comprehensive site assessment.

Comprehensive site assessment should be undertaken by an interdisciplinary team of researchers/experts together with local people. Involvement of local people in field data collection (e.g. measuring trees, assisting in social surveys and ground validation of land uses and maps) inculcates a sense of ownership and induces efforts towards voluntary replication and indigenous innovations. Comprehensive site assessment has two major components:

- *Biophysical characterization.* Vegetation analysis can be done through rapid appraisal or rigorous assessment following a statistically efficient sampling design. It should capture the historical changes in land-use systems and landscape structure and function. The assessment should cover topography, hydrology, sedimentation, contamination, climate and ecosystem structure and processes. Participatory resource mapping and key informant interviews can supplement/complement the scientific data.
- *Socioeconomic characterization.* Participatory Rural Appraisal (PRA) is an effective tool of capturing the level of awareness of the value of mangroves, local needs and priorities. Demographic (population, gender distribution, ethnicity, etc.), socioeconomic (income and livelihood), and cultural profiles (traditional use and management of

mangroves) and existing institutional arrangements in managing mangroves such as property rights and stewardship arrangements must be analyzed for improved mangrove resource utilization and management practices.

3.2.c Participatory mangrove rehabilitation planning.

Rehabilitation planning starts with a Problem Tree Analysis. A good understanding of the problem root causes is critical to designing appropriate rehabilitation strategies. Results of the comprehensive site assessment provide insights about the key site-specific management issues. Visioning exercise, which aims to solicit a standard and ideal vision for the mangrove forest, follows the problem analysis. Such a unified vision is further interpreted into long term goals and achievable objectives over the short term in project mode operations. Stakeholders then proceed with strategic planning exercises. The following are the major components of the technical rehabilitation guidelines:

» *Correct site selection*. Mangrove planting should only be done within the middle to upper intertidal zones of the coastal area where mangroves naturally grow and thrive (Primavera et al., 2012). Moreover:
  › Original mangrove sites (including those that are abandoned fishponds after conversion) should be the target of rehabilitation and not habitats such as seagrass beds.
  › Mangrove sites vary in sizes from tiny strip to several thousand hectares. Careful planning is needed taking into account the operational constraints of time, budget and human resources.
  › Correct information about the site's ecology and hydrology is vital in designing rehabilitation programme. Planting on the wrong site, at the wrong time, with the wrong species leads to failures. In summary: a) get the hydrology right; b) do not start by planting mangroves: first, find out why mangroves are not there; c) see if the reason for mangrove absence can be corrected; if not choose another site; d) use a reference site to identify the conditions suitable for mangroves in the project area; e) for the reference site, be clear about its topography before considering another area; and f) evaluate costs and benefits early in project planning to maximize cost-effectiveness.

» *Nursery management.* Size, cost and location of nursery depend on the amount of planting materials to be produced to complete the rehabilitation target. Nursery should be established in a strategically located area that is near the seed or wildling source, sheltered from strong waves and close to plantation sites. Tending of seedlings largely includes watering, cleaning, and hardening-off to ensure vigour. Seedling transport may be needed if planting site is far.

» *Outplanting*. This generally involves: a) selection of appropriate species for planting; b) configuration of species in mixed planting and spacing (number of seedlings per unit area); c) planting schedule taking in account tides; and d) selection of planting techniques.

» *Site maintenance*. Key activities include removal of algae and barnacles on seedlings, establishment/maintenance of wave barriers and gap-filling.

» *Field monitoring*. Regular monitoring is essential to check if rehabilitation objectives are met. Ocular inspections over extensive areas and census of survivors and their height, main stem and canopy growth in selected areas enable cost-effective monitoring and corrective actions.

3.2.d Participatory project implementation

» *Forging agreements with partner governments and academic institutions*. This involves several meetings with key local government officials, NGOs and academic institutions to convey concerns for pursuing rehabilitation and clarification of property rights and roles that the community will play in rehabilitation. Eventually, an agreement (e.g. Memorandum of Agreement or resolution) with important stakeholders (particularly local community) could be sought to ensure provisions of sustained support or commitment to rehabilitation.

» *Community organization (CO) and strengthening communications*. COs should immerse themselves in the local partner community to gain an in-depth understanding of local needs, strengths and opportunities. Once COs have a thorough feel for these aspects, they can conduct capacity building activities such as People's Organization (PO) formation, leadership training, and livelihood training. One of the major goals of these activities is to increase local awareness/knowledge about the importance of mangrove conservation, and how such endeavours will uplift their general well-being. Cross-site visits, hands-on training on mangrove ecology, nursery management, and site monitoring can be made available to the local community to further equip them with necessary technical knowledge.

- *Community mobilization*. The local community should be mobilized in conducting their project planning, implementation, and monitoring and evaluation. In some cases, organized communities are tapped as partners in government mangrove planting projects, thus providing additional income source.
- *Mainstreaming rehabilitation strategies*. Memoranda, partnerships and other forms of agreements on mangrove rehabilitation should be further elevated into local government resolutions or ordinances to incorporate rehabilitation in community-led local development plans.

3.2.e Participatory monitoring and evaluation.

Monitoring project progress, vis-à-vis satisfaction of objectives and targets by the local community and partner institutions, is vital to elicit measures to keep the project on track. Mutual sharing of information is an effective way of promoting transparency and commitments.

3.3 Suitability of the proposed mangrove rehabilitation guidelines: Case studies in the Philippines and Myanmar

In the Philippines, three case studies were completed to assess the applicability of the mangrove rehabilitation guidelines. These included: 1) Katunggan Ecopark at Leganes, Iloilo (a joint scheme of local community,

FIGURE 3. The Philippine Research Team with stakeholders at Katunggan Ecopark at Leganes, Iloilo.

FIGURE 4. The Philippine Research Team with stakeholders at Barotac Nuevo, Iloilo.

local government unit (LGU) and a Non-Governmental Organization viz., the Zoological Society of London (ZSL); 2) Taklong Island Marine Reserve in Guimaras Province (Scheme: local community in partnership with the Department of Environment and Natural Resources, or DENR); and 3) Jalaud Mangrove Rehabilitation in Barotac Nuevo, Iloilo (Scheme: local community in partnership with the Iloilo State College of Fisheries).

As a background, rehabilitation project in Leganes in Iloilo started in 2009. It began with the initiative of the ZSL. In Taklong Island Marine Reserve (TINMAR) rehabilitation was led by the DENR in response to an oil spill disaster in 2006 and as a component of the National Greening Programme (NGP) in 2011. Lastly, rehabilitation efforts in typhoon-damaged fishponds of Barotac, Nuevo, Iloilo started in 2013 as part of the national aquasilviculture programme of the Bureau of Fisheries and Aquatic Resources (DA-BFAR). Photos of these sites during field data collection of the Research Team are presented in Figures 3 and 4.

In Myanmar, the Myeik Forest Department organized the Taw HtwinGyi Community Forestry in 2016 to initiate community-based mangrove rehabilitation efforts in Myeik Township, Tanintharyi Region.

Results of the case study showed that before the establishment of Community Forestry, mangroves were cleared for urban expansion and agriculture. The lack of community ownership or tenure rights over mangrove areas was noted as the major challenge in promoting mangrove conservation. Mangrove rehabilitation was mentioned as an offshoot of the community forestry programme in partnership with local people, Myeik Forest Department officials, and NGOs namely, Myanmar Green Network (MGN) and Flora and Fauna International (FFI).

Table 2 summarizes the key activities and practices in view of the proposed mangrove rehabilitation framework. Results showed that rehabilitation was unlikely to succeed if people were excluded from the planning and monitoring process or, alternatively, were involved solely in the capacity as implementers of top-down decisions, an approach which was widespread until recently. Thus, wholehearted and committed participation of local communities is a prerequisite for successful rehabilitation, and this participation can be secured by actively involving people in the planning and monitoring process. It was also evident that mangrove species differed with respect to their adaptation to salinity and flooding and had a narrow range of tolerance in the establishment phase. There is an urgent need for enhancing silvicultural knowledge of mangroves, an aspect neglected in the past, to increase the effectiveness and efficiency of rehabilitation. These conclusions are

Steps in mangrove rehabilitation	***Philippines case studies***			***Myanmar case study***
	Katunggan Ecopark at Leganes, Iloilo	***Taklong Island Marine Reserve (TINMAR), Guimaras***	***Barotac, Nuevo, Iloilo***	
Local site coordination	ZSL initiated consultations with the LGU of Leganes. Consent was then secured from Barangay Nabitasan and Guaa represented by the Barangay captains in the form of a formal Memorandum of Agreement in 2009.	Under DENR-NGP, local site coordination was done by the stakeholders within the two barangays, namely Lapaz and San Roque within TINMAR. Local people organizations were tapped as direct collaborators of NGP Following a series of consultations and meetings with the POs were conducted.	Orientation was conducted before project implementation. The LGU was in-charge of the coordination while the Iloilo State College of Fisheries (ISCOF) provided training through funding from the Bureau of Fisheries and Aquatic Resources (BFAR) with the fisherfolks as direct beneficiaries.	Myeik Forest Department officials facilitated the consultation and coordination activities with communities using the funding assistance of NGOs. The community decided to establish community forestry to protect the remaining natural mangroves and to rehabilitate the depleted areas.
Comprehensive site assessment	At the start of the project, the needs and interests of the communities were not assessed, nor their understanding of mangrove ecosystems. Thus, the community members did not feel any form of ownership. This was one of the reasons why the people were organised into an association relatively late in the project because the LGU did not see the enthusiasm in the local people to participate in the project until the mangrove forest was starting to grow back.	TPOs were not in site assessment. Rapid assessment in response to the oil spill was only initiated by the technical staff of PENRO Guimaras, but hydrology patterns, slope and topography in the area were not considered. Under the DENR-NGP, different institutions were considered, such as the National Mapping and Resource Information Authority (NAMRIA) for the land use survey, mapping and zoning. The University of the Philippines Visayas was also tapped to do the socioeconomic and demographic survey.	There was no inspection on the condition of mangroves before the rehabilitation, although socio-economic surveys were performed by the academe in the community. The members of the PO, on the other hand, had many ways to assess if the site was appropriate for planting, one of which was when the fruit has already fallen.	Forest Department organised the site assessment team which includes the Taw HtwinGyi community forestry management committee members, representatives from MGN and FFI. However, the team did not involve scientists such as marine biologists or zoologists.
Participatory mangrove rehabilitation planning	Key problems and underlying causes that contributed to mangrove deforestation were not discussed among interest groups. Activities were planned by LGU and ZSL and implemented by the community.	POs within TINMAR were not involved in the planning process. During site selection and setting of targets, community members were informed through several FGDs.	PO was involved in the planning process.	MGN and FFI facilitated the participatory development of the management plan for the Taw HtwinGyi Community Forestry. The management plan was developed by the management committee.
Participatory project implementation	From 2009 to 2013, rehabilitation efforts involved more than a thousand volunteers and planted almost 60,000 seedlings in the site. However, it was only during the stage implementation when the community members realised the benefits that could augment their livelihood through tourism, food catering and recreation.	POs were directly involved in the implementation process from nursery management, planting and mangrove monitoring. Meetings for updating and regular sharing of information were conducted. Technical training was also conducted, such as hands-on training on GPS reading, tagging, bagging, identification of seeds, nursery management, and mangrove pest diseases prevention and control.	Meetings were held once a month wherein the process of seedling production and planting were among the topics discussed. Capacity-building activities were conducted as part of the project's implementation.	Forest Department provided two training activities on nursery management and seedling production. Aside from the technical support, training and facilitation were also provided by the FFI, MGN and as well the Forest Department.
Participatory monitoring and evaluation	PO participates in the monitoring and evaluation of seedlings planted, primarily to assess if replacement planting is needed. However, they do not have a monitoring and evaluation plan. The project was deemed successful since it has brought back the mangrove.	Both POs in TINMAR were trained on how to assess the health of mangroves planted under the NGP project. Thus, they also participated in monitoring. Part of this activity is the replacement or replanting of dead seedlings.	PO members were given the task of monitoring the site, while the LGU conducts weekly visits. Likewise, BFAR conducts monitoring, although rarely.	Taw HtwinGyi community has organised an internal audit team following the Community Forestry Instructions. The audit team not only audits financial matters but also monitors and assessed the activities of the community. However, they do not have a systematic framework for monitoring and evaluation.

TABLE 2. Testing the applicability of proposed mangrove rehabilitation guidelines in the Philippines and Myanmar.

corroborated by the reports of Walters (2004), Samson and Rollon (2008), Primavera and Esteban (2008), and Thompson, Clubbe, Primavera, Curnick, and Koldewey (2014).

4. CONCLUSION

Mangrove rehabilitation should be understood as an inherently slow, expensive, complex and uncertain process. Rehabilitation demands: 1) integrated and ecosystem-based approaches taking into account feedbacks between rehabilitation, other land/aquatic resource uses, and non-land/ocean-based economic activities; 2) widening the scope of rehabilitation beyond merely planting; 3) participation of local people in planning and monitoring in addition to implementation; 4) clarity in the roles and responsibilities of different stakeholders; and 5) selection of plantation species based on ecological and silvicultural knowledge in conjunction with the needs and priorities identified by the stakeholders. In summary, ensuring sustainable and effective mangrove rehabilitation, active collaboration among government, non-government organizations, funding agencies, and research institutions and, most importantly, by local communities is vital.

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Environmental and economic impact assessment of the Low Emission Development Strategies (LEDS) in Shanghai, China

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ABSTRACT

National action on climate change and international negotiations are interlinked and mutually reinforcing. The international negotiations in the past years have stimulated national action, especially on Low Emission Development Strategies (LEDS) meaning development with the minimal output of emissions. This research will try to develop effective science-policy interaction to discuss the opportunities where LEDS can be used to support energy system, environmental, and economic development planning strategies in the city of Shanghai, China. In this paper, we argue that the urgency of bold and timely LEDS coupled with the social, environmental, and economic opportunities. With this in mind, we elaborate an interest-oriented approach to mobilizing multiple benefits of the Shanghai Master Plan as one of the essential LEDS in this city and argue that multiple benefits assessments can be important drivers of ambitious and effective social policy.

KEYWORDS

Impact assessment, Low Emissions Development Strategies, Shanghai, Urban energy system

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HIGHLIGHTS

- By the implementation of LEDS through slower socioeconomic development and stronger energy efficiency policies, the cumulative carbon emissions can be reduced by approximately 17.6 $MtCO_2$-eq.
- LEDS present excellent opportunities to contribute significantly to job creations and raise GDP by the tertiary sector.
- Shanghai's government should continue to pursue its policy to relocate its heavy industry to make room for the tertiary sector.

1. INTRODUCTION

The concept of LEDS has been included in the negotiating texts under the United Nations Framework Convention on Climate Change (UNFCCC) since the run-up to COP15 in Copenhagen in 2009 and is part of both the Copenhagen Accord and the Cancun Agreements (UNFCCC, 2011), which recognize that LEDS is indispensable to sustainable development and that incentives are required to support the development of such strategies in developing countries. In practice, the plans are often combinations of new and existing elements, all combined in a new way to address pre-existing policy objectives along with the need to slow climate change and prepare for its impacts. A growing number of international organizations and consultancies have also been involved in LEDS, including the UNDP, UNEP, the World Bank (including through its Energy Sector Management Assistance Program [ESMAP]), Climate Works, the Climate Development Knowledge Network, World Wide Fund for Nature (WWF), the European Union and a variety of bilateral donors. Japan currently has an edge in the majority of environmental and energy technologies. However, it is vital to layout medium- to long-term LEDS to keep responding to global needs in the future and contribute to the reduction of 50% global GHG emission by 2050.

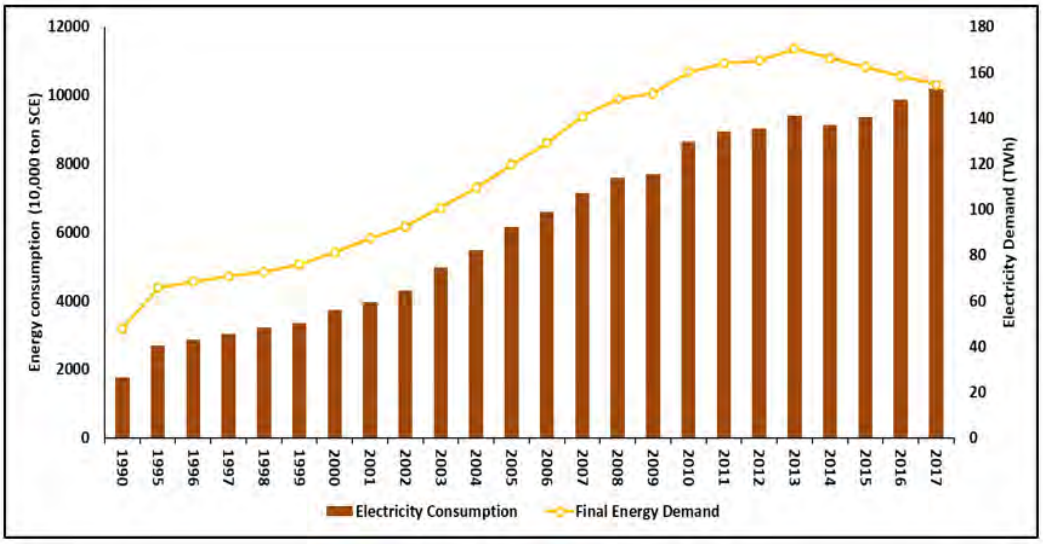

FIGURE 1. Trends of final energy and electricity demand in Shanghai (Shanghai Municipal Bureau of Statistics, 2017).

1.1 Policy structure and LEDS in Shanghai

Shanghai is one of the four direct-controlled municipalities of China, with a population of more than 26.3 million as of 2018, rendering it the most populous city in China. Shanghai covers an area of 6,340 km^2, and is divided into 16 districts. The centre city of Shanghai bounded with the outer ring road covers an area of 660 Km^2 (Cui & Shi, 2012). According to the latest issued Shanghai 2035 Master Plan, Shanghai has different management policies and planning targets upon the different spatial scales of the city (WWF, 2012). Shanghai shows one growing city power in the global cities network with rapid social-economic development in recent years. In the 2011-2016 Global Power City Index (GPCI) issued annually by Mori Memorial Foundation, Japan, Shanghai's rank in 40 global cities grew from 26th place in 2011 to 14th in 2013 and 12th in 2016, with the comprehensive power comparison including economy, research and development, culture interaction, livability, environment and accessibility (Yamato, Hamada, Matsuda, Dustan, & Taki, 2017). With the rapid growth of the population and urbanization in recent years, the demand for energy has also increased, resulting in the growth of the total energy consumption in Shanghai. The six drivers include (1) population and urbanization, (2) economic growth, (3) industrial structure, (4) technology progress and innovation, (5) welfare, and (6) energy supply structure. These main drivers impact Shanghai's energy consumption and related emissions. Shanghai's economy has built up in the post-1978 reform era. Its GDP increased from 25 billion CNY in 1995 to 494 billion CNY in 2018 (Census and Economic Information Center, n.d.). The historical trends of final energy demand and electricity consumption are depicted in Figure 1 which shows the rapid growth of energy consumption from 2001-2010, with the highest growth rate in 2005 of up to 9.2 %., After that, energy consumption decreased in the period 2011-2015 (Shanghai Municipal Bureau of Statistics, 2017). Among all sectors in Shanghai, the industry sector, including the mining, manufacturing, power, and construction accounts for the largest consumer of energy, followed by the transport sector and other sub-sectors in the tertiary industry. Energy supply mainly relies on fossil energy and electricity imported from other provinces, and the share of new energy is still negligible.

The strong vertical linkage between the central government and local government provides the favourable institutional setting for LEDS experiments. In China, municipal authorities are required to achieve targets set by the central government, although the actual input may vary greatly depending on their level of motivation and capacity. There are three layers of plans in the policy related to spatial planning and territorial development in China; socioeconomic development plans, national spatial plans (land use plans), and urban and rural plans. Socioeconomic development plans are drafted at the national, provincial, prefectural and county levels. Urban and rural plans can be divided into urban system plans, urban plans, town plans, township plans, and village plans. Urban and rural plans are drafted at the national, provincial, prefectural, county, township, and village levels (see Figure 2). Such an institutional setting leaves much room for local governments to conduct policy experiments aiming at policy learning while fulfilling the task. Shanghai is designated as a Pilot Low-carbon City, which opened opportunities for various policy experiments to incubate innovations. With the city's efforts, several creative policy practices emerged in Shanghai, e.g., introducing regular planning cycle at a local level, and going beyond the top-down target (Cheng, Kamath, Rowe, Wood, & Yue, 2014). In this sense, the vertical

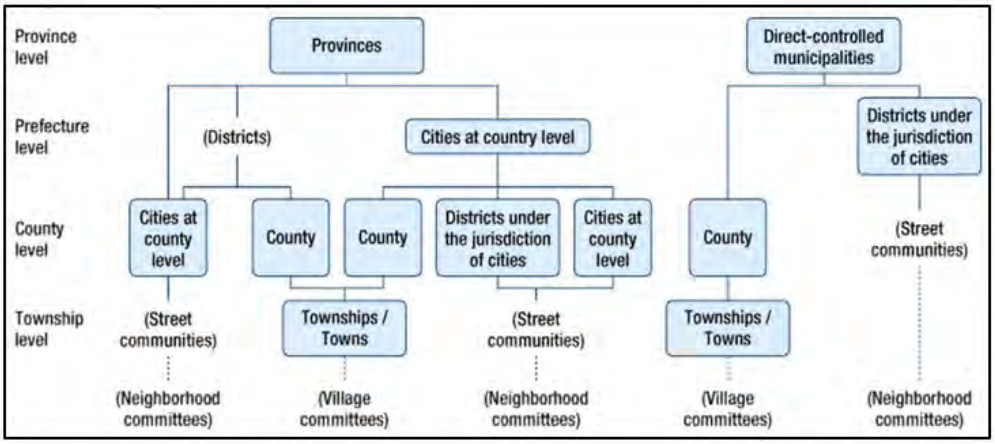

FIGURE 2. Structure of local authorities in China (Cheng, Kamath, Rowe, Wood, & Yue, 2014).

cooperation of governments across levels presented in the case of Shanghai is facilitated by the institutional setting in China.

There are several characteristics of Shanghai's LEDS, as summarized below. The city's LEDS are embedded and integrated into the existing policy framework instead of an entirely new strategy. LEDS in Shanghai can be divided into two stages:

1. **The implicit stage**: Before 2009, which is the implicit stage, Shanghai has been on its way to adjusting industrial structure, improving energy efficiency and controlling air pollution, etc., the co-benefits of which contribute to GHG control.
2. **The explicit stage**: The Shanghai LEDS were precisely introduced as an integrated policy strategy, tackling multiple challenges in this city. The LEDS were rooted in the city's existing policy framework. The approach of hooking "low-carbon" onto other local policy schemes is common and not necessarily initiated in Shanghai. However, Shanghai's LEDS are more than re-interpreting traditional policy schemes with low-carbon implication, but with new low-carbon policy measures such as local pilot low-carbon developing districts, and carbon labelling.

Shanghai LEDS to reduce its energy-related challenges are divided into the following categories:

- » Developing renewable energies,
- » Increasing gas supply, and
- » Improving energy efficiency, particularly in industries, transport, and buildings.

2. METHODOLOGY

To evaluate the multiple benefits of the implementation of LEDS in Shanghai, a city-level CGE (computable general equilibrium) model was developed based on the general equilibrium theory. It uses actual economic data from a SAM (Social Accounting Matrix) which is an accounting framework that reflects the circular flow of city's economic activity to estimate how a city might react to changes in clean energy policies. The CGE model has two main parts: supply and demand. On the supply side, the microeconomic principles have been utilized to develop a concept that would represent the behaviour of an urban energy system in a market with perfect competition. The local government, as a decision-maker in this market, strives for maximum satisfaction (minimization of the total cost) of delivering certain energy services to the end-users, such as providing required electricity at the end-user level (Farzaneh, Doll, & Puppim de Oliveira, 2016). The modelling approach used to formulate the above concept is given below (Farzaneh, 2017a):

$$MinTotalCost = \Sigma_i F_i p_i \tag{1}$$

Subject to:

$$f(F_i, \dots, F_n) \geq D^* \tag{2}$$
$$\Sigma_i F_i \leq R_i \tag{3}$$
$$F_i \leq L_i \tag{4}$$
$$F_i \geq 0 \tag{5}$$

F_i: Production factor *i* (such as energy, material and capital)

D^*: Given demand for the utilities

R_j: Available resource of production factor *i*

L_i: Bound on using or consumption of production factor *i*

P_i: Unit cost of determinant factor *i* (i.e. cost of technologies and energy carriers)

On the demand side, a spreadsheet simulation model based on bottom-up end-user method and the Avoid-Shift-Improve (A-S-I) approach was applied to the end-user level (buildings, transport, and waste) to assess the effect of different scenarios of socioeconomic, technological, and demographic developments on energy consumption and emissions of the city-wide energy system in a multi-sectoral context (Farzaneh,

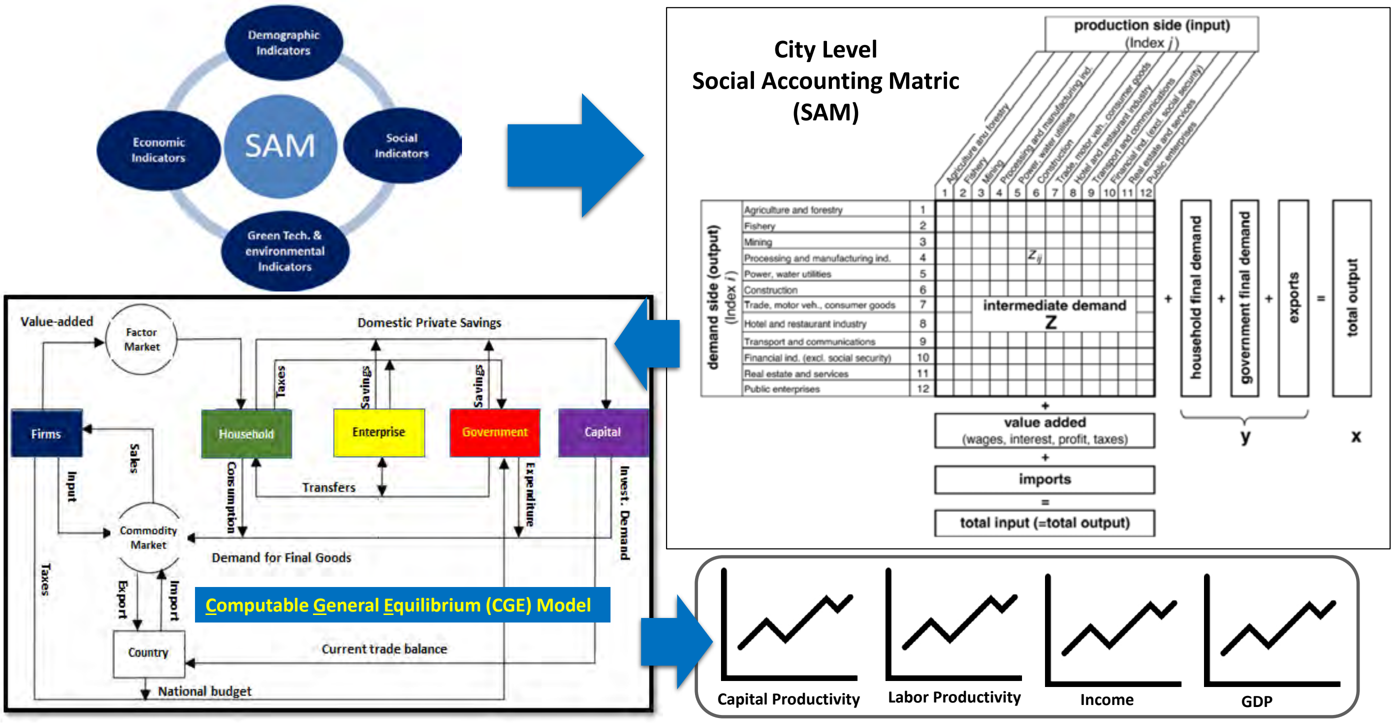

FIGURE 3. CGE model developed in this research.

2017a). The model systematically relates the GHG and air pollution emissions based on the specific energy demand in the end-user sectors in cities to the corresponding social, economic, and technological factors that affect this demand (Figure 3). The CGE model was implemented as a mixed-integer linear programming problem using the GAMS (General Algebraic Modelling System) to find the minimum total cost of delivering a certain level of energy service through the optimal combination of available technologies and resources in the urban energy system (Farzaneh, 2017b; Farzaneh, 2019).

3. RESULTS AND DISCUSSION

3.1 Key drivers of Shanghai's LEDS

Population and economic growth are the two main drivers that are behind Shanghai's urban expansion.

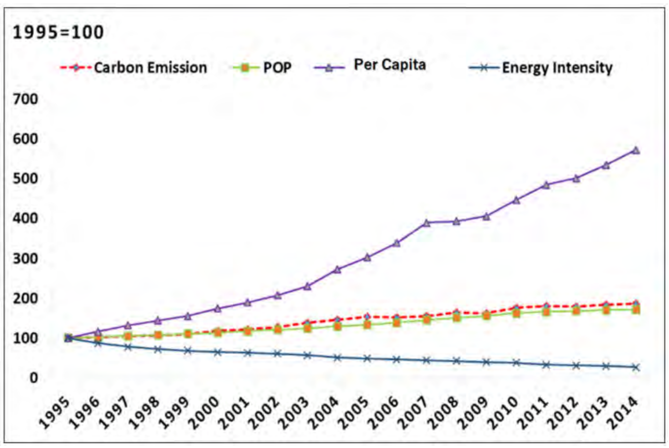

FIGURE 4. Key drivers of Shanghai's carbon emissions.

Both population and economic growth in Shanghai have moderated since their height in 2007, yet both remain high, generating continued pressure on urban infrastructure. Figure 4 shows that as energy intensity decreased over the period, the economic growth partially decoupled from energy use. The combined growth in population and per capita GDP led to a dramatic increase in carbon emissions in this city between 1995 and 2014. Increases in population and per capita GDP result in more production and consumption activities, which, in turn, raise energy consumption and emissions. While Shanghai's energy intensity decreased by 77%, this improvement in energy efficiency had minimal impact on carbon emissions, which means that most of the energy efficiency improvement is offset by increased energy consumption.

The results of the analysis of the historical trends of carbon emissions, population, per capita GDP, foreign direct investment and the different sector's share of GPD are reported in Table 1.

	Elasticity
Population	0.1747
Per Capita GDP	0.3862
Primary sector's share of GDP	0.0100
Secondary sector's share of GDP	0.2950
Tertiary sector's share of GDP	-0.0959
Foreign direct investment	0.0624

TABLE 1. Carbon Intensity Elasticities in Shanghai.

Among the variables, per capita GDP (0.386), population (0.175), secondary sector's share of GDP (0.2950) and foreign direct investment (0.0624) are positively correlated with carbon emissions, whereas the tertiary sector's share of GDP is negatively correlated (-0.0959). Shanghai's economic development has led to increased construction and land use development in both the residential and commercial sectors over the last few years. The increase in economic growth also brought forth Foreign Direct Investment (FDI), which has contributed to the higher energy consumption and carbon emissions of Shanghai. The secondary sector comprises energy-intensive, fossil fuel users and plays a leading role in increasing carbon emissions through enhancing both direct and indirect consumption resulting in increased carbon emissions. The negative value for the tertiary sector shows that the growth of this sector based on modern, knowledge-intensive, and service-based, has been effective in reducing carbon emissions. Therefore, Shanghai's government should continue to pursue its policy to relocate its heavy industry to make room for the tertiary sector. Moreover, the local government needs to strengthen its economic restructuring policy, not only rely on technological improvements alone to reduce carbon emissions.

Objective	*Target*
Population Control	Population resident will be controlled at 25 million by 2040
Construction land control	Construction land will be controlled at 3,200 km^2 by 2040
Public transportation coverage	Length of Railway (designed speed as 100-250 km/h) planned to be more than 1,000 km
	Length of subway (designed speed as 80km/h)and light rail (60-80 km/h) increases to 1,000 km
	Use of public transportation reach to 50% in main urban zone
	Use of green transportation researches up to 85% by 2040
	The density of rail transit increases to 1.1 km/km2 in the city centre
	Rail transit accessible for the new town with a population more than 100,000
Green Space increase	Public green space per capital reaches to 15 m^2 by 2040
	Forest coverage area reaches to 25%
	Public green space per capital reaches to 7.6 m^2 by 2040
Green Building Construction	All newly built buildings should completely meet the green construction standard
Air Quality Improvement	The annual average concentration of PM2.5 which is controlled at 25 μg/m^3
Renewable energy and Climate Change Mitigation	The share of renewable energy reaches 20% in the total primary energy supply mix
	Total carbon emission reduces to 85% of the peak emission by 2040

TABLE 2. Main objectives and targets in Shanghai Master Plan 2016-2040.

3.2 Shanghai Master Plan

According to the Shanghai master plan, the local government aims at introducing measures for controlling the population growth and construction in this city, which will result in improving public safety and local air quality. The detailed information about the Shanghai Master Plan 2016-2040 is given in Table 2 (Leading Group Office of Shanghai Master Plan, 2015).

Required data for the multiple benefits assessment of the Shanghai Master Plan were mainly drawn from government statistical yearbooks. Shanghai's energy data can be found in the China Energy Statistical Yearbooks (National Bureau of Statistics of China, 2018). Other statistics for Shanghai, including GDP, population, sectoral output, government investments in the environment, and foreign direct investment were obtained from the Shanghai Statistical Yearbook (Shanghai Municipal Bureau of Statistics, 2017). To simulate future changes in carbon emissions, we compared the results of the Shanghai Master Plan with three scenarios of future socioeconomic development. Among all determinants in all scenarios, GDP and population are the most important ones.

Meanwhile, the results reveal that energy consumption and renewable energy generation significantly affect carbon emissions in Shanghai. Based on the findings discussed above, four planning indicators were selected for scenario construction. The predicted values of these planning indicators were based on expert workshops and interviews with the local experts and also literature reviews. Accordingly, the average annual GDP growth rate for Shanghai is expected to be approximately 7% for 2016-2020 and 6% for 2020-2040 (Shanghai Municipal Bureau of Statistics, 2017). The indicators of population growth rate, GDP growth rate, Annual decrease rate of energy consumption and growth rate of the share of renewable energies in total energy mix were adjusted as shown in Table 3 to obtain the following four scenarios: slower socioeconomic development, rapid socioeconomic development and the master plan which was defined as a slower socioeconomic development with reinforced energy efficiency programs.

As shown in Figure 5, future carbon emissions in Shanghai show an increasing trend in all scenarios. The baseline scenario predicts that the cumulative carbon emissions will reach 114.7 $MtCO_2$-eq., while three scenarios predict emissions of 103.8 (Slow Socio),

	Baseline	*Slow Socio*	*Rapid Socio*	*Master plan*
Average annual growth rate of permanent population (%)	1	0.5	1.3	0.5
Annual GDP growth rate (%)	7	6	8	6
Annual decrease rate of energy consumption (%)	-5	-5	-5	-6
Share of Renewable energy in total supply (%)	<1	<1	<1	20

TABLE 3. Scenario definition for the LEDS assessment in Shanghai.

122.8 (Rapid Socio), and 97.1 (Master plan), respectively. The master plan predicts the least amount of carbon emissions. Comparison of the master plan and the baseline scenario reveals that with slower socioeconomic development and stronger energy efficiency policies, the cumulative carbon emissions can be reduced by approximately 17.6 $MtCO_2$-eq. Thus, reinforcing energy efficiency policies through relocating the carbon-intensive industries and making room for the knowledge-intensive and service-based tertiary sector could have a significant impact on reducing the total carbon emissions in Shanghai. Although current energy efficiency policies in electricity generation and industries in Shanghai are contributing to total carbon emission mitigation, it is difficult to ignore the fact that a high rate of socioeconomic development will increase carbon emissions in the absence of a major breakthrough in energy-saving technologies. This indicates that the implementation of the Shanghai master plan leads to more efficient resource use, and merely curbing the economic development and population growth does not improve efficiency and may even reduce the efficiency of resource use. The comparison between the energy mix in the baseline scenario and the master plan is represented in Figure 6. This effect is due to the rate of GDP growth being slower than the rate of carbon emissions growth as shown in Figure 7.

The major reduction in coal consumption is expected from boosting green mobility, shutting more outdated steel and coke capacity and gradually improving clean coal's share in the industry sector through replacing it with natural gas and alternative fuels.

The decline in the total amount of carbon emissions from the major sectors such as iron and steel complexes, power plants, transport sector, service sector, chemical industries, and other sectors, compared to the baseline scenario is expected to be approximately 2.8, 5.6, 4.9,

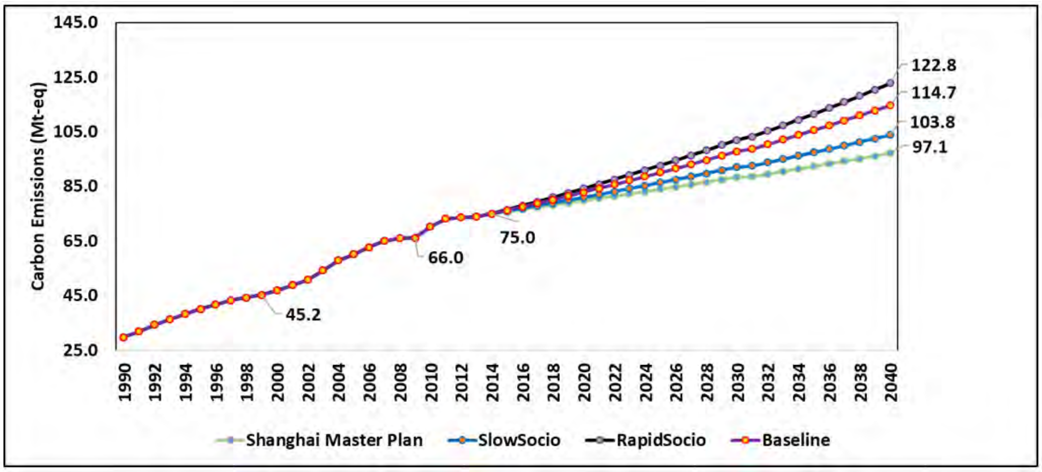

FIGURE 5. Prediction of carbon emission in the different scenarios.

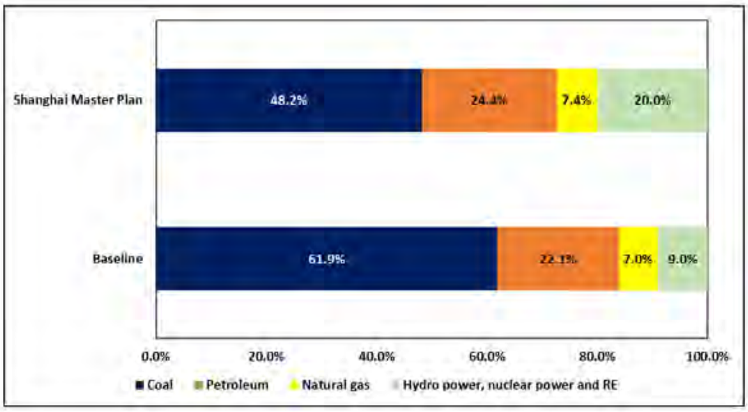

FIGURE 6. Comparison between energy mix in the baseline and the master plan.

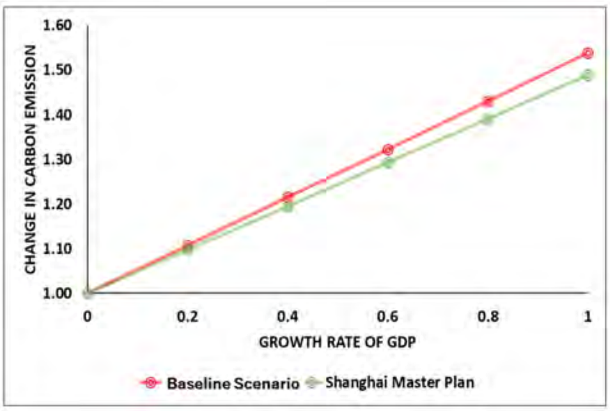

FIGURE 7. Change in carbon emission vs. the growth rate of GDP.

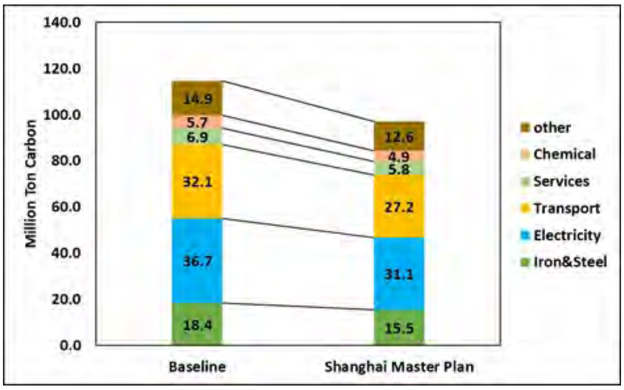

FIGURE 8. Sector-wise comparison between carbon emission in the baseline and the master plan.

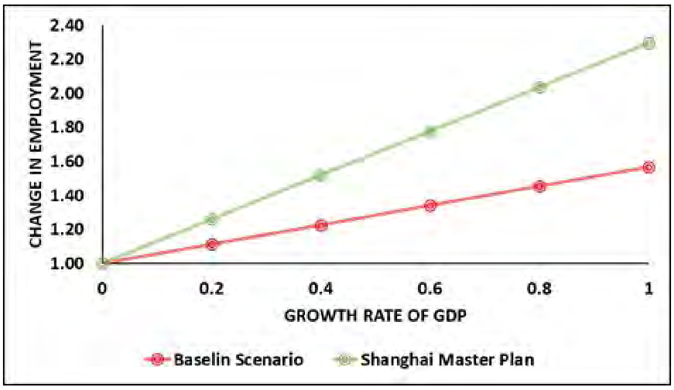

FIGURE 9. Change in employment vs. the growth rate of GDP.

1.1, 0.9 and 2.3 $MtCO_2$-eq, respectively (Figure 8). As coal has often been criticized for its higher impact on the environment, Shanghai has made a move to close down smaller old coal-fired plants to open bigger high technology ones that not only have higher capacities but are also more energy-efficient. In fact, the older coal-fired plants are estimated to consume 30-50% more coal than newer models. While they make up for half of Shanghai's yearly coal use, they can only generate 30% of Shanghai's total power supply. For Shanghai Municipality, all power plants with small generation units of 2.108 GW shall be shut down during the implementation of the master plan. The Three Gorges Dam mainly generates the 8,000 MW of Shanghai's imported power. Acceding to the master plan, Shanghai municipality is supposed to import more hydropower, which is considered as renewable and clean energy to reduce its controversial high share of coal-generated power. Shanghai municipality will increase the wind power installed capacity to 200-300 MW in 2030.

Nevertheless, offshore wind farms bear a higher potential for Shanghai in the future. While Shanghai tries to promote clean energies, it must be noted that the main goal will remain to ensure power supply security. Even state authorities acknowledge that renewable energies will only play a marginal role in the future, mainly because of higher generation costs and lack of space. Shanghai Municipality is favouring the extension of the domestic natural gas network as it is considered cleaner energy. Thus, efforts are made to increase the population's access to natural gas, especially in populated areas. Comparison of the Shanghai master plan and other scenarios also shows that reinforcing energy efficiency policies will have positive effects on per capita carbon emissions and per unit GDP carbon emissions, and the lowest per capita carbon emissions occurred in the master plan. Hence, controls on economic development and population growth are essential in reducing total carbon emissions in Shanghai. However, it is challenging to realize sustainable socioeconomic development by controlling only economic development and population growth. Therefore, to achieve more sustainable and environmentally friendly socioeconomic development, evaluating the economic and social benefits of the Shanghai master plan is essential. Implementation of the Shanghai master plan presents excellent opportunities to contribute significantly to the job creations and raise GDP by the tertiary sector to increase the share of green employment in Shanghai total workforce by 46% in 2030, if LEDS technologies are acquired by China (Figure 9).

4. CONCLUSION

In this research, three scenarios of slower socioeconomic development, rapid socioeconomic development and the shanghai master plan, which was defined as a slower socioeconomic development with reinforced energy efficiency programs were considered. The significant reduction in coal consumption is expected from boosting green mobility, shutting more outdated steel and coke capacity, and gradually improving clean coal's share in the industry sector through replacing it with natural gas and alternative fuels. In Shanghai, reinforcing LEDS will have positive effects on per capita carbon emissions and per unit GDP carbon emissions. Evaluation of the Shanghai Master Plan in Shanghai showed that the growth of the tertiary sector based on modern, knowledge-intensive and service-based would result in increasing the multiple economic-environmental benefits from this plan. Therefore, Shanghai's government should continue to pursue its policy to relocate its heavy industry to make room for the tertiary sector. Moreover, Shanghai's local government needs to strengthen its economic restructuring policy, not only rely on technological improvements alone to reduce carbon emissions.

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Water-energy-food nexus perspective: Pathway for Sustainable Development Goals (SDGs) to country action in India

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ABSTRACT

Water, energy and food securities lie at the heart of the Sustainable Development Goals (SDGs). Since these securities are interconnected, the business-as-usual approach (sectoral approach) cannot achieve them and need to apply the water-energy-food nexus approach for identifying and overcoming the roots of barriers and challenges. The study aims to prioritize interlinkages between SDG-2 (food security), SDG-6 (water security) and SDG-7 (energy security) for country action. In order to achieve this aim, the study implements a set of methods including stakeholder perception survey, network analysis, regression analysis and cross-sectorial group discussion. This article summarizes the outcomes of a case study in India. Stakeholders cognition derived through scrutinizing the perception survey admitted the need for a nexus approach in the action plans towards the SDGs. Quantitative assessment of interdependency showed that, of 182 interlinkages between SDG-2, SDG-6 and SDG-7 targets, 124 interlinkages had synergistic relation. The combined outcome of the cross-sectorial group discussion identified eight interlinkages as high priority ($p>0.9$) for immediate integrated planning and action. A total of ten interactions are moderate ($p=0.6$ to 0.9) and eight are low priority interlinkages ($p<0.6$). Solid understanding of synergies and trade-offs associated with SDG targets and initial prioritization of interlinkages would help India reorient its SDG priorities from a water-energy-food nexus perspective.

KEYWORDS

Country actions, India, Sustainable Development Goals, Water-Energy-Food Nexus

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HIGHLIGHTS

» Key stakeholders of India have a high level of perception about the interdependency of SDG-2, SDG-6 and SDG-7.

» Out of 182 interlinkages, 124 showed a synergistic relationship, implying that there is a high potential to capture synergies by taking a nexus approach in SDG implementation that can provide effective resource solutions and contribute to swiftly achieving three key SDGs.

» A case study in India identified nine priority targets: T2.1, T2.2, T2.4, T6.1, T6.2, T6.3, T7.1, T7.2 and T7.3. Among interactions between these nine targets, eight interlinkages are identified as high priority ($p>0.9$) for immediate integrated planning and action. A total of ten interactions are moderate ($p=0.6$ to 0.9) and eight are low priority ($p<0.6$).

1. INTRODUCTION

Water, energy and food are the basic needs for all human beings and the fundamental elements necessary for economic growth and development. Despite significant progress, the security of water, energy and food supplies each remain far from being achieved. Notably, in the Asia-Pacific region, millions of people lack basic services (water, energy and food), are deprived of their human rights and are trapped in poverty. About 280 million people lack adequate access to safe water (World Bank, 2018), more than half of the population suffer food insecurity (FAO, IFAD, UNICEF, WFP, & WHO, 2019) and 350 million lack access to electricity (IEA, 2018). It is projected that demand for these three resources will further increase in coming years and meeting such additional demand will be challenging under the conventional uni-sectorial approach. It is envisaged that by 2030, 30% of the world will be faced with water shortage (WWAP, 2015), food demand will increase by 50% (FAO, IFAD, UNICEF, WFP, & WHO, 2017) and energy consumption will increase by 30% (IEA, 2017). With Asia and the Pacific taking a leading role in terms of economy and development, the continuing growth in population will place immense pressure on these resources, which will lead to increasing conflict.

The role of food, water and energy are justifiably accorded critical status in the approved Sustainable Development Goals (SDGs) as they are crucial for sustainable development, and specific goals and targets have been set for these three key sectors. Water, energy and food are not isolated but are inextricably linked. Concerns expressed in the literature emphasize the relevance of water, energy and food linkages not only for poor people who have limited access to water, energy and food of insufficient quality but also for fast-developing regions with a rapidly growing demand for these three elements (Bazilian et al., 2012; Hoff, 2011; ICIMOD, 2015; Waughray & Workman, 2011). Going forward, ignoring this interdependency will only create further contradictions and lead us away from the bedrock principle of sustainable development (Merrey, 2015). A water-energy-food nexus provides a basis which can be considered inevitable in the implementation of the SDGs (Salam, Pandey, Shrestha, & Anal, 2017; Rasul & Sharma, 2016; Gallagher et al., 2016).

The most important challenge is how global ambition should be interpreted at the national level. Hence, the Open Working Group for the SDGs emphasized setting up national targets, taking into account the national context such that these targets can be elaborated with indicators. The water-energy-food nexus approach is compatible with this principle and will help identify suitable sets of actions for specific countries (or regions) (Weitz, Nilsson, Huber-Lee, Davis, & Hoff, 2014). The ultimate aim of the water-energy-food nexus approach is to maximize synergies through strengthening cross-sectoral integration, which leads to an upgrade of resource management to enhance water energy and food security (Scott, Crootof, & Kelly-Richards, 2016). To date, much discussion has taken place at international and regional levels but has mostly dealt with issues at the conceptual level. In most cases, policy and development choices are made on a unilateral basis, and the lack of knowledge on water-energy-food nexus has often led to mismatches in prioritization and decision-making, which will hinder sustainable development. Asia and the Pacific SDGs progress report 2019 reported that the region could not make sufficient progress to achieve resource-related SDGs, thus greater efforts are needed (UNESCAP, 2019).

Funded by the Asia-Pacific Network for Global Change Research (APN), we conducted this study in three emerging countries of Asia including Bangladesh, India and Viet Nam to identify priority SDG targets and understand interlinkages between SDG-2 (food security), SDG-6 (water security) and SDG-7 (energy security). Finally, the study attempted to identify priority interlinkages between targets for integrated action that would guide SDG implementers to design action effectively and meet the related targets swiftly. This article will focus on India as a case study. For the other two case studies, please refer to the full research report (Kuyama et al., 2019).

2. METHODOLOGY

To meet the objectives of this research, the study team relied on several methods such as stakeholder survey, networking analysis, regression analysis and cross-sectoral group discussions.

2.1 Stakeholder perception and network analysis

A questionnaire survey was conducted, targeting all relevant ministries and governmental departments, NGOs, academia related to water, food and energy, to analyse stakeholder perception on the importance of nexus aspects for the country actions on SDG-2, SDG-6 and SDG-7. The first part of the questionnaire sought perception of stakeholders on the interdependency of SDGs and targets on “No hunger”, “Clean water and sanitation” and “Energy security” goals and targets. This was followed by part-2 related to country’s readiness to implement a nexus approach in country actions. Responses of the questionnaire were quantified by converting the response in terms of quantitative value. The following quantification was used for various responses to prepare network maps. The value assigned to the strong opinion is 3.0, moderate opinion is 2.0, weak opinion is 1.0, and for no link, it is 0. Then, the weighted average was taken to link each of the three SDGs with targets of the remaining two SDGs. This was followed by a network analysis using Social Network Visualizer (SocNetV) software to visualize relationships between SDG-2, SDG-6, SDG-7 and its relevant targets. SocNeV is freely available at https://socnetv.org/downloads.

2.2 Quantitative assessment of interlinkages among the SDG targets on water, energy and food security

Quantitative aspects of the interlinkages are addressed by using statistical techniques to test hypotheses on possible associations among indicators of water, food and energy goals. Results of this analysis are important in determining whether and to what extent one indicator quantitatively correlates with the others. The identified linkages between the targets have been validated using Pearson's correlation coefficients and were obtained through pairwise comparison of those indicators with their statistical significance. For time series (from 2000 to 2015) regression, relevant data were collected from various sources as mentioned in Kuyama et al. (2019). The linkages among SDG-2, SDG-6 and SDG-7 were analysed through pairwise correlation among the indicators which measured these targets. This pairwise correlation describes the direction of linkages between the two variables. Pearson's correlation provides a measure to evaluate the strength of an association between two variables. Pearson's correlation analysis can capture nonlinear correlations between variables and is less sensitive to outliers (Hauke & Kossowski, 2011). In Pearson's correlation, a p-value of less than 0.05 is considered as statistically significant. In this study, a p-value greater than 0.6 is considered to indicate a synergy (positive association) between two indicators, a p-value less than -0.6 is considered to indicate a trade-off (negative association), and a p-value between -0.6 and 0.6 is considered to indicate a non-classified.

2.3 Prioritization of interlinkages for actions

The proposed research involved a stakeholder survey in collecting feedback on the results of network analysis and regression analysis. It also aimed at prioritizing country actions based on the key stakeholders' perceptions and preferences. For this, an international workshop was organized on 25–26 June 2019 at Central University of Rajasthan, India. This workshop aimed to bring together and engage a wide range of stakeholders — government agencies, academic and research communities, civil societies, NGOs, international organizations and young professionals — on a common platform. Participants were divided into three groups with respect to SDG-2, SDG-6 and SDG-7 to prioritize and rank the top three targets from each goal based on their importance, status and national development strategies and priorities. After the group work, all three groups provided their final priorities and ranking of targets. A matrix was prepared for the prioritized targets and their correlation values (from the previous section) and further refined in priority based on the correlation values (Table 1).

The analysis provides a shortlist of indicators, which are measurable and fully reflect the proposed relevant targets as well as interdependent nature among the approved water, food and energy goals. Consequently, this list of indicators can help to manage water, food and energy effectively and meet related SDG targets more rapidly.

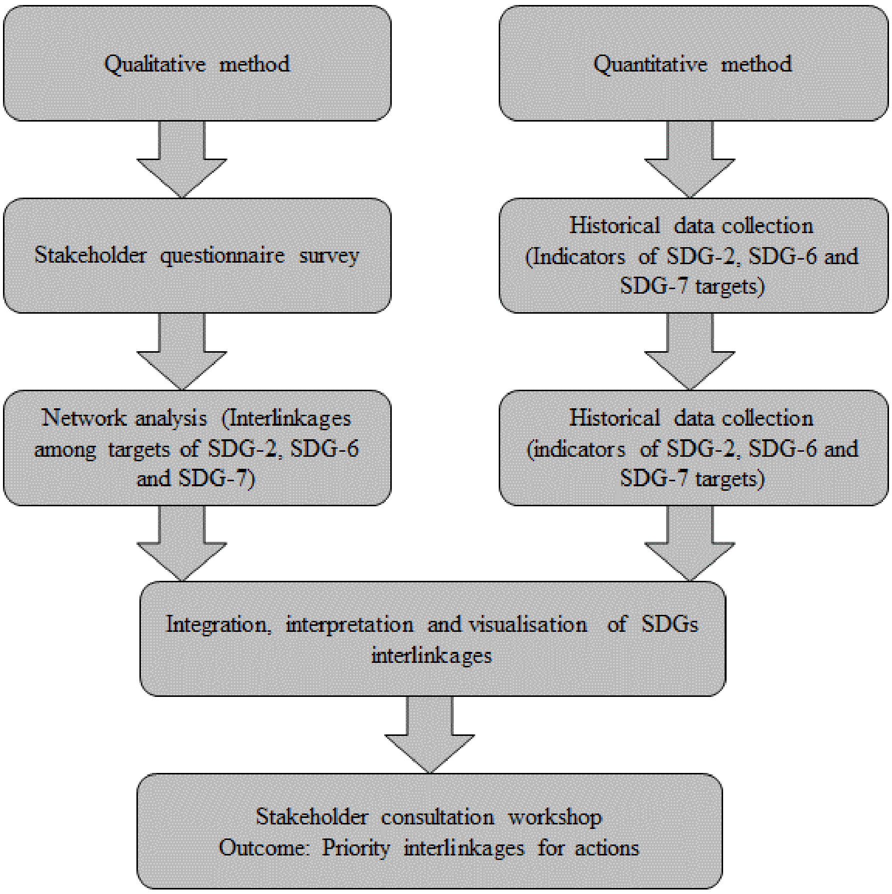

FIGURE 1. Methodological framework of the study.

P-value	***Priority level***
>0.9	High
0.6 – 0.8	Moderate
<0.6	Low

TABLE 1. Matrix to prioritize interlinkages of targets.

3. RESULTS AND DISCUSSION

3.1 Stakeholder perception on interdependency of SDG targets on food, water and energy security

Figure 2 (a) shows the stakeholder perception on the dependency of SDG-2 on targets of SDG-6 and SDG-7. According to the results of the questionnaire survey, stakeholders believe that the achievement of SDG-2 is highly dependent on the three water security-related targets (T6.1, T6.3 and T6.4) with the highest weightage value of 2.63. Stakeholders' perception shows that energy security-related targets do not have a significant effect on SDG-2.

Figure 2 (b) shows the dependency of SDG-6 on targets of SDG-2 and SDG-7. Width of the lines indicates the strength of dependency. Stakeholders' perception results show a strong dependency of SDG-6 on various targets of two other goals, including T2.1, T2.4, T2.2, and T7.1. The result implies that the implementation of SDG-6 should be integrated with different targets of SDG-2 and SDG-7.

In case of the dependency of SDG-7 on targets of SDG-2 and SDG- 6, the stakeholders' perception indicates that energy security is also highly dependent on various water targets including T6.3, T6.4 and T6.1 (refer to Figure 2 (c)).

The stakeholders' perception, as mentioned above, indicates that stakeholders believe there is an interdependency of water, energy and food security. The next section will determine whether and to what extent one target quantitatively correlates with the others.

3.2 Quantitative assessment of interlinkages among the SDG targets on water, energy and food security

The quantitative relationship among different targets has been examined to understand synergy or trade-off relationships among SDG-2, SDG-6 and SDG-7 targets which provide useful insight to identify priority interlinkages. Linkages among the three SDGs were analysed through pairwise correlation among the indicators measuring these targets. Pairwise correlation describes the direction of linkages between two variables. The interaction between target pairs of SDGs was split into three categories: synergy, trade-off and non-classified. For the Pearson's correlation, a p-value greater than 0.6 is considered to indicate a synergy (positive association) between two indicators, a p-value less than -0.6 is considered to indicate a trade-off (negative association), and a p-value between -0.6 and 0.6 is considered to indicate a non-classified.

The pairwise correlation coefficients with their statistical significance level are shown in Table 2. The p-value ranges from -0.87 to +1.0. Out of 182

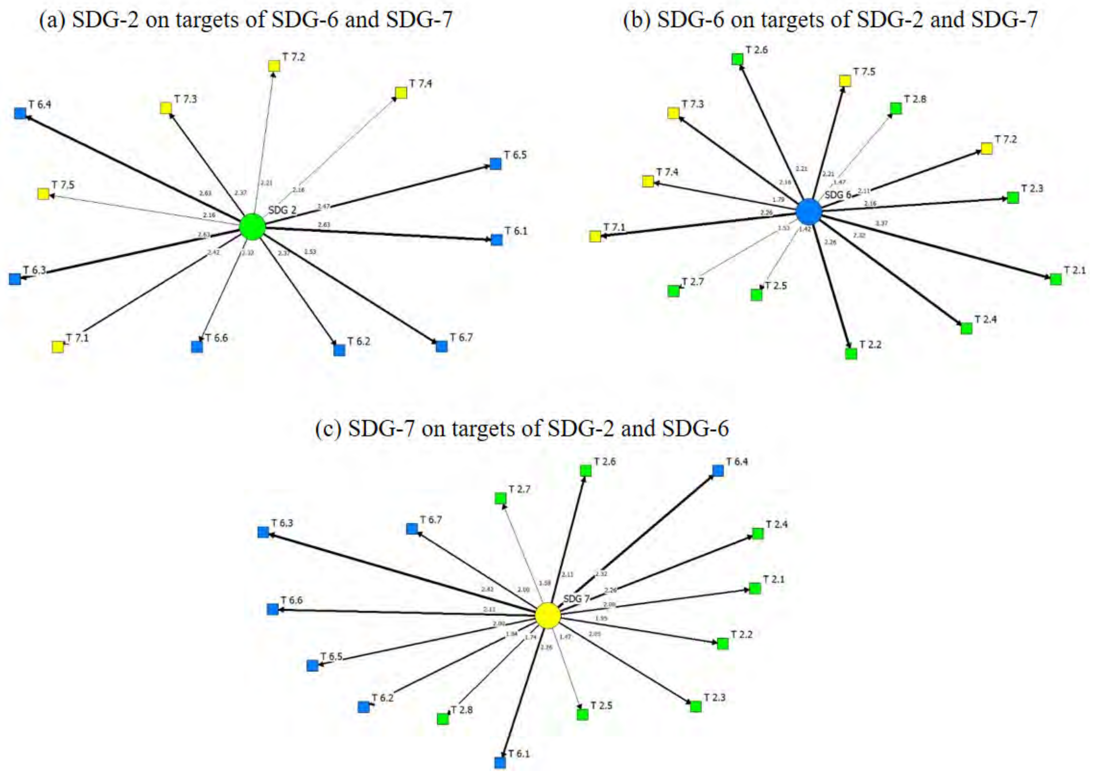

FIGURE 2. Visualisation of stakeholders' perceptions on the dependency of SDGs of food, water and energy on targets of other goals.

	T2.1	T2.2	T2.3	T2.4	T2.5	T2.a	T6.1	T6.2	T6.3	T6.6	T6.a	T7.1	T7.2	T7.3
T2.1	1.000	.785**	.740**	-0.137	.879**	.698**	.787**	.790**	.974**	.944**	.713**	.730**	.730**	.719**
T2.2	.785**	1.000	.720**	0.094	.899**	.863**	-0.239	.996**	.958**	.936**	.856**	.940**	.940**	.713**
T2.3	.740**	.720**	1.000	-0.250	.799**	.606**	-0.342	.679**	-0.184	.736**	.662**	.636**	.636**	.594*
T2.4	-0.137	0.094	-0.250	1.000	0.125	0.223	-0.018	0.062	0.777	-0.149	-0.092	0.152	0.152	0.067
T2.5	.879**	.899**	.799**	0.125	1.000	.850**	-0.158	.889**	0.000	.922**	.783**	.826**	.826**	.569*
T2.a	.698**	.863**	.606**	0.223	.850**	1.000	-0.268	.864**	0.767	.830**	.740**	.869**	.869**	.642**
T6.1	.787**	-0.239	-0.342	-0.018	-0.158	-0.268	1.000	1.000**	-0.697	-0.313	-0.339	-0.272	-0.272	-.847**
T6.2	.790**	.996**	.679**	0.062	.889**	.864**	1.000**	1.000	.969**	.896**	.842**	.943**	.943**	.977**
T6.3	.974**	.958**	-0.184	0.777	0.000	0.767	-0.697	.969**	1.000	0.583	0.708	0.807	0.807	0.769
T6.6	.944**	.936**	.736**	-0.149	.922**	.830**	-0.313	.896**	0.583	1.000	.688*	.776**	.776**	0.524
T6.a	.713**	.856**	.662**	-0.092	.783**	.740**	-0.339	.842**	0.708	.688*	1.000	.750**	.750**	.710**
T7.1	.730**	.940**	.636**	0.152	.826**	.869**	-0.272	.943**	0.807	.776**	.750**	1.000	1.000**	.704**
T7.2	.730**	.940**	.636**	0.152	.826**	.869**	-0.272	.943**	0.807	.776**	.750**	1.000**	1.000	.704**
T7.3	.719**	.713**	.594*	0.067	.569*	.642**	-.847**	.977**	0.769	0.524	.710**	.704**	.704**	1.000

TABLE 2. Pairwise Pearson's correlation among various targets (2000-2015). Statistical significance level of correlation coefficients have been presented in asterisks: $p > 0.6$ (synergies); $p < -0.6$ (trade-off) and p -0.6 to 0.6 (non-classified). ** Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).

interlinkages, 124 showed a synergistic relationship. This implies that there is a high potential to capture synergies by taking the nexus approach in SDGs implementation that can provide effective resource solutions and help to achieve three key SDGs. It is also important to identify trade-off interlinkages to manage the negative effect of one SDG target on other targets. In total, there are three interlinkages which displayed a trade-off relationship. It is unrealistic to suggest that any of the country studies incorporate all synergistic and trade-off interlinkages in the implementation of the SDGs. Therefore, it is important to prioritize interlinkages for immediate response, medium-term response and long-term response. The next section will prioritize the interlinkages for the country actions.

3.3 Prioritization of interlinkages for actions

Cross-sectoral group discussion prioritized the targets of each SDG based on certain justifications. Table 3 presents the prioritized targets of each SDGs with their possible justification. Some other linkages were revealed among the targets of each SDG, the awareness of which is important in order to implement plans and actions properly. This is considered necessary to achieve the targets and goals.

Based on the p-value in Table 2, a correlation matrix was prepared to classify the interlinked targets into different classes, i.e. high, moderate and low priority (Table 4). Interlinked targets with high priority are more important as there is high synergy, which can help in achieving goals more quickly and help address injudicious use of financial and natural resources. High priority interlinked targets are marked with three asterisks (***), whereas a single asterisk (*) indicates poorly correlated targets.

Target T2.2 is strongly correlated with other SDG targets like T6.2, T6.3, T7.2, T7.1. Similarly, target T6.2 is strongly correlated with all three energy targets. This means that there is a need to focus on these interlinked targets to accelerate the cumulative impact on water-energy-food security of the country.

4. CONCLUSION

Water, energy and food are basic elements for survival and essential for economic growth and sustainable development. Therefore, the importance of water, energy and food security has been well recognized in the approved SDGs, including SDG-2 (food), SDG-6 (water) and SDG-7 (energy). The world has been facing various challenges of security of these three resources; particularly, with Asia and the Pacific region taking the leading role in terms of economy and development. The continuing growth

Target	*Target Description*	*Remark*
	SDG-2	
T-2.4	By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production.	If production is not ensured, what should we make available to eat? Identify food crops which are adapted to the local climatic conditions and can also grow in case of limited water or other resources. Conserve the environment and natural resources.
T-2.1	By 2030, end hunger and ensure universal access to nutritious and sufficient food.	Food is essential for ensuring labour productivity.
T-2.2	By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under five years of age.	To ensure a healthy population for future generations.
	SDG-6	
T-6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all.	Consider the main priority to provide equitable access to safe and affordable water for society's well-being and good health.
T-6.2	By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.	To ensure a healthy population for future generations and reduce society vulnerabilities.
T-6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and the release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.	Improved water quality is a concern as it will help in the protection of freshwater resources and the use of treated wastewater.
	SDG-7	
T-7.2	Increase the share of renewable energy in the global energy mix substantially by 2030.	To improve the status of other targets, it is important to have more sources of renewable energy.
T-7.1	By 2030, ensure universal access to affordable, reliable, and modern energy services.	To ensure the overall development of society.
T-7.3	Double the global rate of improvement in energy efficiency by 2030.	To ensure proper use and saving of energy with reduced wastage.

TABLE 3. List of prioritized targets with their justification (from group discussion).

	T2.4	T2.1	T2.2	T6.1	T6.2	T6.3	T7.2	T7.1	T7.3
T2.4	-	-	-	-0.081*	0.062*	0.77**	0.15*	0.15*	0.07*
T2.1	-	-	-	0.79**	0.79**	0.97***	0.73**	0.73**	0.71**
T2.2	-	-	-	-0.23	0.99***	0.96***	0.94***	0.94***	0.71**
T6.1	-	-	-	-	-	-	-0.27*	-0.27*	-0.84*
T6.2	-	-	-	-	-	-	0.94***	0.94***	0.97***
T6.3	-	-	-	-	-	-	0.80**	0.80**	0.76**
T7.2	-	-	-	-	-	-	-	-	-
T7.1	-	-	-	-	-	-	-	-	-
T7.3	-	-	-	-	-	-	-	-	-

TABLE 4. Pairwise Pearson's correlation among prioritised targets. *** High priority (>0.9); ** Moderate priority (0.6-0.8); * Low priority (<0.6).

in population will place immense pressures on these resources, which will lead to increasing conflicts unless integrated planning and decision-making framework are incorporated in development pathways. Stakeholders' cognition derived through scrutinizing the perception survey revealed essential aspects to incorporate nexus aspects in the action plans towards the SDGs. In the case of India, quantitative assessment of interdependency showed that, out of 182 interlinkages between targets of SDG-2, SDG-6 and SDG-7, 124 interlinkages have synergistic relation. Since the SDGs are interdependent, under the business-as-usual approach, the country cannot achieve them. Hence, an integrated approach is required, and a water-energy-food nexus approach can provide an entry point to capture and utilize potential synergies in the implementation of SDG-2, SDG-6 and SDG-7 collectively. An integrated strategic planning process for capturing synergies and minimizing trade-offs in priority interlinkages among the goals and associated targets would help India to achieve co-benefits and strengthen institutional coordination for mainstreaming coordinated actions on SDGs (e.g. NITI-Aayog and Ministry of Finance of India can lead the process). In order to create a foundation for integrated strategic planning on SDGs, a capacity building programme for policy- and decision-makers is needed to provide a better understanding of interlinkages across the SDG goals and targets. Introducing incentive-based budget allocation mechanisms will recognize and emphasize cross-sectoral planning and coordinated actions on priority interlinkages.

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Evaluation of best management practices with greenhouse gas benefits for salt-affected paddy soils in South Asia

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ABSTRACT

Anthropogenic climate change has caused increased soil salinity in South Asia due to saltwater intrusion caused by sea level rise, input of fertilizers with high salt index, and irrigation malpractices, etc. Salinity has a multitude of impacts on plant and soil processes, leading to alterations in gas fluxes and rice productivity. The remedial measures adopted on salt-affected soils to reduce the salinity effect could enhance future climate change if they cause an increase in greenhouse gas (GHG) emissions. This study was conducted to find the best agricultural management practices (BMPs) for salt-affected soils in rice cropping systems (i.e. the major cropping system in Asia) in four South Asian countries (Sri Lanka, India, Bangladesh and Pakistan) considering net GHG emissions and other socioeconomic benefits associated with the adopted measures. The salinity-affected sites were selected based on available information (e.g. agricultural statistics and maps). Site-level measurements on soil parameters and GHG emissions were made in control- and managed plots and farmer surveys were conducted. Although organic amendments ameliorated salinity, it could cause a net increase in carbon dioxide or methane emissions depending on the soil conditions, particularly during the initial stages. This impact could be ameliorated by combining organic amendments with other management practices. In the Indo-Gangetic region, poor soil drainage causing anaerobic conditions favoured nitrous oxide emission under low to medium salinity. Yield losses and emissions in high salinity sites were controlled through organic amendment, irrigation and rice-fallow cropping sequence. The combination of transplanting of rice seedlings, the addition of organic matter, and intermittent irrigated water levels was identified as the BMP for Sri Lankan farmers. The outcome of this project will be used to raise awareness among farmers and policymakers.

KEYWORDS

Agriculture, Climate change, Greenhouse gas emissions, Management practices, Salinity

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HIGHLIGHTS

- Both organic and inorganic amendments can variably increase greenhouse gas emissions in salt-affected soils.
- Organic amendments could improve the soil conditions, and yield in salt-affected sites when combined with proper water management and other agronomic practices.
- Transplanting seedlings help minimize yield loss in saline soils compared to broadcast seeding.

1. INTRODUCTION

South Asia is responsible for about one-third of the global rice production and about one-fifth of the global wheat production among a variety of other crops (Food and Agriculture Organization [FAO], 2015). However, food security in the region is affected due to unfavourable impacts of climate change, including land degradation, and increased salinity in agricultural soils has been a significant concern. The agricultural areas within the countries in the region are variably affected by saltwater intrusion due to sea-level rise and certain irrigation practices.

A significant part of agricultural lands in this region, particularly in Bangladesh, India, Pakistan, and Sri Lanka are already witnessing soil salinity as the major challenge for crop production. In Sri Lanka, about 0.1 million ha of paddy lands are affected by salinity (De Alwis & Panabokke, 1972), and coastal salinity mainly exists in districts of Mannar, Puttalam, Jaffna, Trincomalee, Ampara, Hambantota, Galle, Kalutara and Matara (Senanayake, Herath, Wickramesinghe, Udawela, & Sirisena, 2017). India has 6.73 Mha salt-affected soil, including in coastal areas, of which 2.5 Mha lies in the Indo-Gangetic plain (IGP) (Singh, Arora, Mishra, Dixit, & Gupta, 2019). In Bangladesh, about 30% of the arable land is in the coastal zone, of which about 1.2 Mha soil has become saline (Islam, Salambr, Hassanbr, Collardbr, & Gregorio, 2011). Salinity intrusion in Bangladesh is also partly due to the conversion of cropland to shrimp farming and overexploitation of natural resources.

Soil salinity is one of the most devastating environmental stresses, which causes a significant reduction in cultivated land area, productivity and quality (Shahbaz & Ashraf, 2013). Saline soil is defined as soil having an electrical conductivity of more than 4 dS/m in the saturation soil extract at 25°C (Richards, 1954), which is equivalent to ~0.3 dS/m in 1:5 (soil:water) extract (Dharmakeerthi, Indrarathne, & Kumaragamage, 2007). Apart from yield reduction, excess salt interferes with the microbial activity and thus, microbe-mediated soil processes are also affected (Tejada, Garcia, Gonzalez, & Hernandez, 2006). Salt concentration may have significant effects on emissions of GHGs, including nitrous oxide (N_2O) and carbon dioxide (CO_2) (Setia, Marschner, Baldock, Chittleborough, & Verma, 2011).

Crop production, especially the production of rice, which serves as the staple food in the region, has already been severely affected by soil salinity. In this study, we mostly focused on management practices that could ameliorate coastal salinity caused by saltwater intrusion due to sea-level rise, while minimizing GHG emissions in the rice cropping systems. Further, inland salinity was considered for some critical salinity-affected regions such as the IGP.

Management practices could significantly impact GHG emissions from agricultural soils (Lokupitiya & Paustian, 2006). Currently, countries in the region have adopted a range of salinity management practices including salt-tolerant varieties, irrigation water management, crop intensification, and other changes in cropping patterns (i.e. double cropping) and tillage practices, in addressing salinity issues (Sirisena, Rathnayake, & Herath, 2010; Abedin & Shaw, 2013). Recent studies indicate that certain cultivation systems and management practices could help the soil to act as a significant GHG sink (Pandey, Agrawal, & Bohra, 2013). However, remedial measures adopted in salinity-affected soil could enhance or feedback on future climate change if they cause high levels of net GHG emissions.

The intensification of rice cultivation to meet the needs of the population each year may contribute about 1-2% to the observed gradual increase of atmospheric methane (CH_4) mixing ratio (Rasmussen & Khali, 1981). Similarly, the fertilizer use and other management options can lead to variation in the emissions of other GHGs, including N_2O and CO_2. Therefore, the main objective of the current study was to identify the best agronomic practices causing the lowest levels of GHG emissions and best yields in salinity reclaimed land in the respective countries of the South Asian Region.

2. METHODOLOGY

The available information on coastal agricultural areas facing salinity problem in Bangladesh, India, Pakistan, and Sri Lanka, were collected using published scientific literature, reports and other data sources from Governmental and Non-Governmental Organizations. The information collected was analyzed considering the spatial scale of the problem, history and degree of salinity information, and crops and cropping practices affected (with particular emphasis on rice crops), and any land-use changes due to salinity problems. The salt-affected sites for this study were selected based on such available information, including available maps. Site-level measurements on the relevant parameters were conducted (i.e. soil carbon content, electrical conductivity, pH, temperature, etc.), and in-person surveys were conducted to supplement the existing data available within each country.

Existing information, including the agricultural statistics and information obtained from the officers at the Agricultural Extension Services, were used to collect information on the management practices and socioeconomic data in selected regions and sites in each country.

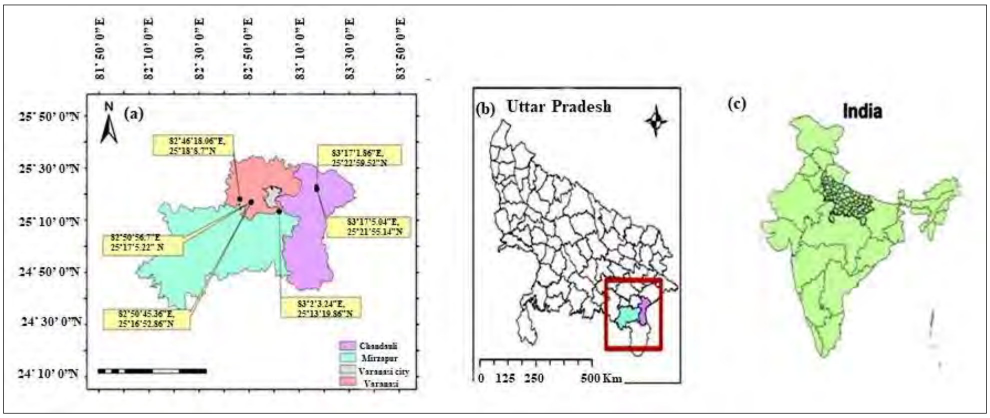

FIGURE 1. The study sites (a) in the state (b) and country (c).

Farmer surveys were executed to obtain relevant information in the selected study areas. The data collected included the location, crop management practices, geophysical variables (e.g. soil type, geographical coordinates) salinity, crop yields and other socioeconomic data including any information on the costs, crop price, farmer income, and fertilizer use, etc.). The farmers' perception of the problem, level of acceptance concerning the adoption of different new management techniques, including advantages and disadvantages, were also documented and studied. The collected data was analyzed both statistically and qualitatively.

2.1 Estimation of GHG emissions (including soil carbon)

Greenhouse gas emissions were measured/estimated using field plots with the chosen BMPs in the respective rice-growing areas within each country. Soil carbon stocks were measured for paired comparison (saline vs non-saline soils and before and after remedial management practices). Similarly, closed-chamber measurements (Hutchinson & Livingston, 1993) of CH_4, N_2O, and CO_2, the three main GHGs emitted from rice paddies, were taken and analyzed using gas chromatography. The number of seasons and sites sampled varied by country, depending on in-country situations, including weather impacts. The collected GHG emission data was analyzed statistically for any significant emission differences with and without the adoption of the chosen BMPs.

2.2 Selected sites and country-specific methodological information

This paper mostly focuses on findings from two of the collaborating countries (India and Sri Lanka), based on the outcome available by the end of the project. The site- and specific methodological information relevant to those countries are given below.

2.2.1 India

Soil samples were collected from a stretch of over 200 km where the salinity-affected land was reclaimed using various agronomic strategies (e.g. organic manure, inorganic N and gypsum salt); then pH, conductivity, cation exchange capacity (CEC), sodium absorption ratio (SAR) were measured. Exchangeable sodium percentage (ESP) were quantified to rank the sites based on the level of salinity. The contour mapping was done to make the salinity level at geographical grids more apparent. Of the mapped sites, six reclaimed land areas were selected for further study (Figures 1 and 2); i.e. Rajatalab (RJT) and Beerbhanpur (BBN) with lower salinity and Mirzamurad (MZM), Baraipur (BRP), Salaempur (SLM) and Dharahara (DHR) with higher salinity (Table 1).

Soil parameters including pH, EC (in 1:5 soil:water extract), texture, and total organic carbon (Walkley

Site	*Clay (%)*	*EC ($dS\ cm^{-1}$)*	*Fertilizers used*	*Irrigation*	*Cation*	*Cropping sequence*
Rajatalab (RJT)	8	0.19	Organic fertilizer	Underground aquifer	K>Mg>Na>Ca	Rice-wheat
Beerbhanpur (BBN)	11	0.34	Mainly chemical	Underground aquifer	Ca>Mg>K>Na	Rice-wheat
Mirzamurad (MZM)	12	0.50	Organic + Chemical	Canal irrigation	Ca>K>Mg>Na	Rice-mustard
Raipur (BRP)	8	1.35	Mainly chemical	Canal irrigation	Ca>Mg>K>Na	Rice-wheat
Dharhara (DHR)	10	1.65	Mainly organic	Canal irrigation	Ca>K>Na>Mg	Rice-fallow
Salaempur (SLM)	12	2.52	Mainly chemical	Canal irrigation	Ca>K>Na>Mg	Rice-wheat

TABLE 1. Characterization of selected sites in India.

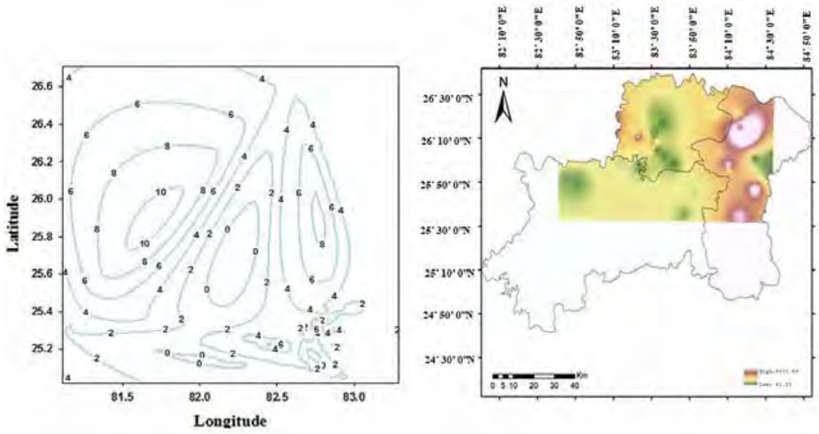

FIGURE 2. Contour map for salinity levels (a) and salinity (in µS cm^{-1}) map of the region (b).

1:5 (soil: water)	*Saturate extract*	*Effect*
<0.15	>2.0	Non-saline
0.16 – 0.30	2 – 4	Slightly saline
0.31 – 0.60	4 – 8	Moderately saline
0.61 – 1.20	8 – 16	Very saline
>1.20	>16	Highly saline

TABLE 2. Salinity ranking based on measured EC (dS m^{-1}) for paddy soils. (Source: RRDC, 2013).

& Black, 1934) were assessed and CEC was measured using ammonium acetate as the cation extractant. The exchangeable cations were then assessed by using an Atomic absorption spectrophotometer (Model Analyst 800, Perkin–Elmer, USA). Cation exchange capacity, SAR, ESP and Exchangeable sodium ratio (ESR) were calculated using a standard formula from exchangeable cations (Harron, Webster, & Cairns, 1983). Total cation concentrations were analyzed with the Atomic absorption spectrophotometer after diacid digestion with a 4:9 ratio of perchloric acid and nitric acid. Anions were estimated by ion chromatography. One-way ANOVA was used to test any differences in sample parameters across the selected sites. The statistical analysis of all data was performed using SPSS (Version 16.0).

2.2.2 Sri Lanka

The salinity levels in several salinity-affected areas of both wet and dry zones of Sri Lanka were measured using soil samples collected at randomly selected sampling locations. Areas of salinity-affected paddy soils in Jaffna and Mannar districts of the Northern Dry Zone of Sri Lanka were identified with the aid of Department of Agriculture, Sri Lanka. Soil samples were collected in the identified locations and tested for soil texture, pH, and electrical conductivity (EC; in 1:5 soil:water extract). Electrical conductivity values were recorded to construct thematic maps of soil salinity. District-wise maps of soil salinity were prepared using ArcGIS 10.0. These maps will be further improved to indicate the different levels of salinity (Table 2).

Soil samples were collected from selected sites in 5 districts in the Wet Zone of Sri Lanka (Table 3). Each site was visited twice a month in two-week intervals and 6 soil samples were collected randomly from each paddy site.

Statistical analyses (i.e. two-sample t-tests) were carried out using Minitab Version 18.0 for comparison of

District	*Site locations**		
Colombo	Kahapola		
Gampaha	Katana		
Kalutara	Walagedara	Iththapana	Paadagoda
Galle	Bentota	Ranthotuwila	Weragoda
	Ambalangoda	Ahungalla	Gonapinuwala
Matara	Dickwella	Godagama	Mirissa

TABLE 3. The sampling sites in the Wet Zone districts of Sri Lanka. *Each location had up to two sites.

saline vs non-saline sites and the salinity levels during the wet period vs dry period at each site. Socioeconomic data was collected from farmers using a questionnaire survey.

The paddy cultivation was dramatically affected by the alternating droughts and floods in the country, and Sri Lanka was ranked second under the Global Climate Risk Index in 2019. The prevailing weather delayed project initiation, and by far the GHG measurements and gas chromatography analyses under different BMPs (along with soil carbon and bulk density measurements) could be conducted at only two sites (Table 4; Figure 3 shows the salinity map relevant to Puttalam District and the site in Madampe). A significant number of sites were surveyed for measuring salinity for map construction during the study period, as described above.

■ *Greenhouse gas measurements in field plots under different BMPs*

Field plots at the selected sites were provided with a combination of different treatments (i.e. a combination of management practices, including one control). The combination of management practices considered the water level until milking (2 cm to 3 cm, intermittent; regular [control]), organic matter (OM) addition (with or without OM), and method of seedling establishment

Soil physicochemical properties	*Madampe*[1]	*Mannar*[2]
Bulk density	0.98 g/cm³	1.23 g/cm³
pH	3-4	5.5-7.5
Soil organic carbon content	0.46%	0.54%
Electrical Conductivity (EC; saturated)	3-4	3-4

TABLE 4. Soil physicochemical properties (0 cm to 15 cm depth) at the beginning of the project at the two experimental sites in dry areas of Sri Lanka, used for GHG measurements. (1) Madampe site (7.4972°N, 79.8413°E) is located on the western coast of Sri Lanka in the intermediate zone with an annual rainfall of 1500-2000mm; (2) Mannar site (8.7748°N, 79.9891°E) is located on the northern coast of the dry zone of Sri Lanka 1-with an annual rainfall of 1000-1250mm in Maha season.

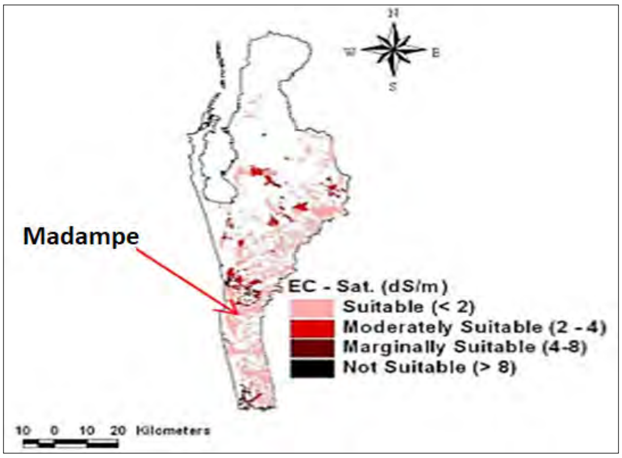

FIGURE 3. Soil salinity map for Puttalam District and Madampe site in Sri Lanka.

(transplanting seedlings vs. broadcast seeding) (Table 5). Newly improved saline tolerant variety BG 310, which has a response for salinity levels up to 8 dSm^{-1}, was estimated in the field plots of the relevant sites. The average crop duration was 100 days. After proper ploughing, puddling and levelling (at the same time compost was also mixed with the soil for the relevant plots), 28-day old seedlings were manually transplanted at a density of 2 seedlings per hill with a spacing of 15 cm x 10 cm (row-to-row and plant-to-plant). All of the field plots were uniform and had the same dimensions (4 m x 5 m). Pest management and weed management were carried out, as needed.

■ *Gas sampling and estimation*

Closed chamber method was used to collect gas samples from field plots. The temperature inside the chamber was measured at every sampling. Samples were collected using a 20 ml syringe at 0-minute, 30-minute and 1-hour intervals (between 11 am to 12 noon weekly). Collected gas samples were analyzed using gas chromatography (Shimadzu Model 9 AM) equipped with a flame ionization detector (FID) and thermal capture detector (TCD).

■ *Socioeconomic analysis*

Socioeconomic data, including information on costs, crop price, farmer income, and fertilizer use, etc., was collected via questionnaire surveys from the farmers in the neighbouring areas of the salinity-affected sites. The information, along with the farmers' perception of the problem, the level of acceptance concerning the adoption of the new management techniques, etc., were collected from a total of 75 respondents. The percentage of respondents falling under the different options for the questions given in the questionnaire survey was analyzed.

■ *Plant growth analysis*

Plant growth parameters (leaf area, leaf number and tiller number) were measured at weekly intervals. Leaf area was measured with a portable laser leaf area meter (Model LI 3000C, USA). The plot-level rice yield was determined by harvesting at the end of the season.

3. RESULTS AND DISCUSSION

3.1 Findings relevant to the study sites in India

In India, rainfall was higher in 2018 than in 2017, but the temperature was uniformly high. Thus, more of the underground aquifer or open canal water was used for irrigation in 2018. Based on the EC and soil sodium concentration, the highest salinity was recorded at SLM followed by DHR, BRP, MZM and BBN and the lowest was found in RJT. In the high salinity areas, canal irrigation is predominant, which probably led to an upward movement of salt by rising groundwater, which is caused due to over-irrigation of the fields. High rainfall in 2018 caused water-logged conditions in high clay containing soil of MZM, SLM and DHR, which resulted in

Agronomic Practice	*Mgt* 1 (a)*	*Mgt 2 (b)*	*Mgt 3 (c)*	*Control (d)*
Water level until milking	2-3 cm	2-3 cm	intermittent	regular
Organic matter addition	Yes	Yes	Yes	No
Broadcast seeding (B) or transplanting (T)	B	T	T	B

TABLE 5. Experimental design showing the combination of practices under the different management options considered.
* Management (Mgt 1, Mgt 2 and Mgt 3) are the management options with different combinations of practices as given, considered against the control plots.

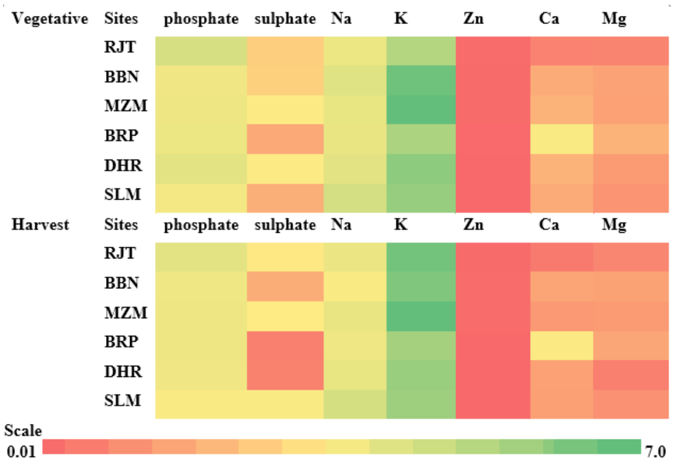

FIGURE 4. Heat map showing variations in phosphate, sulphate, Na, K, Zn, Ca and Mg (mg g⁻¹) contents during vegetative and harvest stages of rice in selected sites in India in 2017.

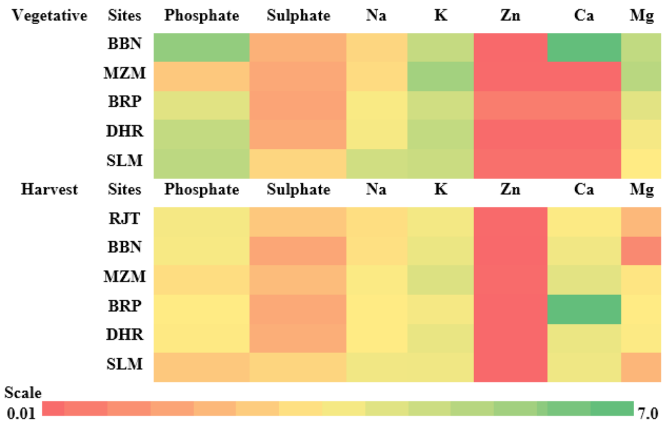

FIGURE 5. Heat map showing variations in phosphate, sulphate, Na, K, Zn, Ca and Mg (mg g⁻¹) contents during vegetative and harvest stages of rice in the selected sites in India in 2018.

the appearance of secondary salinization. Significant increases in rainfall led to increases in leaching, loss of nutrients and increasing acidification depending upon the buffering pool in soils (Karmakar, Das, Dutta, & Rakshit, 2016). MZM showed an increase in sodium (Na) at harvest in 2017 and 2018, while at SLM, Na decreased at harvest in 2017 and increased in 2018 (Figures 3.1 and 3.2). This suggests that poor field drainage even with good rainfall can lead to accumulation of ions thus contributing to salinity. High sulphate ion levels at SLM could be due to the addition of gypsum or pyrite (Figures 4 and 5).

The pH was maximum at SLM followed by DHR and the minimum was at BBN in both 2017 and 2018. The EC of high saline soil was higher during harvest compared to the early stages of growth. On the other hand, at low to medium saline soils, there were no changes in EC. This change reflects the impact of malpractices (untimely addition of inorganic nutrients especially urea) during cultivation in high saline soil.

3.1.1 Greenhouse gas emissions in Indian sites

Sites with low to medium salinity (RJT, MZM and BRP) acted as a source of N_2O during vegetative growth in standing water during rice cultivation. Maximum N_2O emissions were observed at MZM, where maximum clay was observed, and underground aquifer was the source of irrigation resulting in water-logged conditions. Urea and NH_4^+ fertilizer are majorly applied, resulting in higher N_2O emissions under saturated conditions (Tenuta & Beauchamp, 2003). More nitrogen was applied on sites with medium to high salinity to get a better yield. N-fertilizer application during reproductive stage onset led to N_2O emissions at all sites except SLM, with a maximum observed at BRP, which had medium salinity. Nitrous oxide emissions were observed at RJT during all the growth stages (except vegetative stage) which could be due to nitrification by soil microbes.

CO_2 remained positive for most of the duration of rice cultivation and there were no temporal trends. Low saline site (RJT) with high organic carbon, released less CO_2 during the vegetative stage owing to higher utilization efficiency of plants growing under low salinity as well as the waterlogged anaerobic environment created for rice transplantation. Fertilizer application also improves microbial activities resulting in pulses of CO_2 emissions as observed during the pre-reproductive stage upon N-application except at medium saline sites (BBN and BRP), where the peak was instead achieved at the reproductive stage due to poor drainage of the soil. High salinity reduced the utilization efficiency of rice, and thus more input of organic matter and N-fertilizer at saline sites resulted in greater CO_2 emissions.

The sites with low to medium salinity majorly acted as a sink of CH_4 except at the pre-reproductive stage at RJT. The increase in CO_2 at low (RJT) and medium (BBN) sites offsets the CH_4 increase during vegetative growth. High saline soil (SLM) consistently acted as a source of CH4 except during the reproductive stage whereas the least saline soil only acted as a source of CH4 during the pre-reproductive stage. High saline soil (DHR) with better organic amendments disrupted methanogenesis, and thus negative values were obtained at the later stage of growth. The rice-fallow farming sequence and organic fertilizer amendment resulted in a minimum of GHG emissions in saline soil.

3.2 Findings relevant to the study sites in Sri Lanka

The area of the field study in Madampe of Puttalam District has a pH range of 3.0 to 4.0. Only 50 -60% of the crops survived in the broadcasted plots as the plants

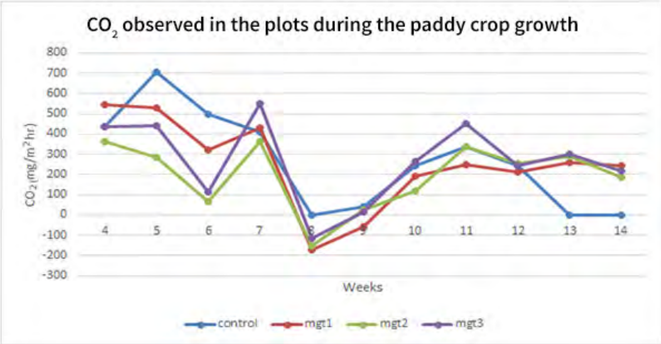

FIGURE 6. CO_2 flux over time in Madampe.

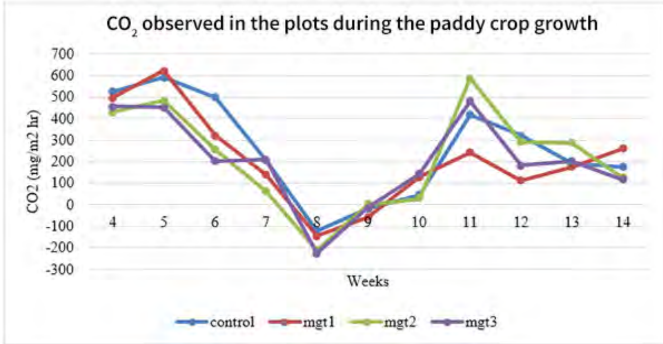

FIGURE 7. CO_2 flux over time in Mannar.

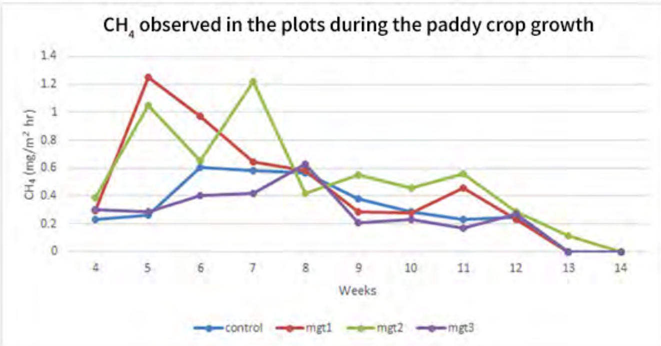

FIGURE 8. CH_4 flux over time in Madampe.

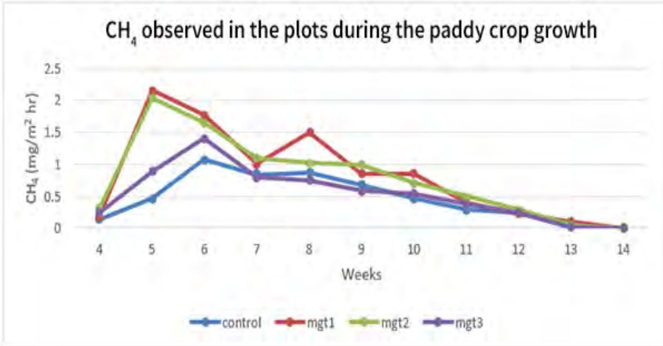

FIGURE 9. CH_4 flux over time in Mannar.

could not tolerate salinity even though 90% of the seeds were germinated. After 14 days the tips of the leaves had burned and eventually wilted.

Salinity tolerance increases with age during the tillering phase of growth and decreases from panicle formation stage to the flowering stage leading to reduced grain yields. The straw weight and the total number of tillers seemed to be less affected than grain yield and the number of productive tillers. According to FAO, high salinity can delay the setting of the inflorescence while increasing the number of sterile spikelets (Abrol, Yadav, & Massoud, 1988). Maintaining the right soil moisture content during the tillering phase to the milking phase would aid in producing higher crop yields. Application of inorganic fertilizers causes N_2O emissions. Organic amendments with intermittent flooding seem to be quite effective in improving salinity while limiting N_2O emissions to undetectable levels, as observed in the current study (data not shown due to insignificant concentrations detected).

CO_2 emissions were observed throughout the rice growth period. High CO_2 flux during the initial growth stages could be attributed to high organic carbon. From the panicle initiation stage to flowering stage CO_2 emission decreased due to the rapid increase in the rate of photosynthesis which eventually decreased towards the harvesting stage (Figures 6 and 7).

Methane emissions gradually increased until the eighth week and then gradually decreased until the 14th week (Figures 8 and 9). Management options that had flooded irrigation showed the highest emission levels.

Preparation of the final salinity maps of Jaffna and Mannar Districts are underway. These maps will be further improved to indicate different levels of salinity, utilizing site-level EC measurements.

3.2.1 Salinity levels in the wet zone of Sri Lanka

The majority of the saline sites surveyed had high salinity, with EC values greater than 0.6 dS m^{-1} in 1:5 extract. The highest salinity levels (over 2.8 dS m^{-1}) were observed at the Kahapola site in the Colombo district during the dry period in August and September in 2018.

According to the statistical analyses, there was a significant difference ($p < 0.05$ for t-tests) between the saline and non-saline soils in the sites surveyed for salinity. In general, all of the districts had higher salinity in August, which is considered a dry month, and the salinity levels were low in May and June. Overall, the salinity in the dry period was comparatively higher than the wet period for all the districts. However, there was no statistically significant difference between the salinity during the dry period and wet period across the majority of the sites. Few sites showed a statistically significant difference between the mean salinity in the wet period and dry period (i.e. reference [non-saline] sites of Kalutara, Colombo, Galle, and salinity-affected sites at Godagama, Mahapalana, and Weragoda).

3.2.2 Findings of the socioeconomic survey

According to the results of the socioeconomic survey, the majority of farmers surveyed do not use salt-tolerant varieties even though the salinity levels are high. Instead, many of them use traditional paddy varieties since they believe them to have a high tolerance for salinity conditions. It was observed that in salinity-affected areas the application of chemical (inorganic) fertilizers by farmers is minimal, and they mostly use a combination of paddy husk, Gliricidia (*Gliricidiasepium*), dried cow dung, and straw to desalinize the land. According to the farmers, leaving rice residue (i.e. straw) in the field after harvesting helps control the salinity levels to a certain extent. Application of gypsum has also helped them reduce salinity levels. Gypsum provides a direct source of calcium ions (Ca^{2+}) to replace exchangeable Na, which can then be leached from the soil with irrigation water or rain (Gharaibeh, Eltaif, & Shra'ah, 2010).

4. CONCLUSION

Reclamation practices adopted by farmers in the IGP region reduces the salinity and improves the rice yield. Underground water irrigation led to a reduction in salinity whereas salinity increases were observed in canal irrigation practices. Soil with high clay content at MZM, SLM and DHR became water-logged resulting in increased salinity. SLM with the highest salinity displayed maximum Na and sulphate ions. Although rice-wheat and rice-fallow are the most common cultivation sequences of the IGP region, the best sequence is found to be rice-fallow with organic amendments and groundwater irrigation with respect to optimum rice yield and controlled GHG emissions. Screening of rice cultivars for controlling GHGs emissions along with optimum inputs needs to be considered in the future to get better returns in terms of yield under different combinations of reclamation strategies.

The salinity levels in non-saline and saline sites studied in Sri Lanka, particularly those in the wet zone, showed a statistically significant difference. The yield losses under saline conditions were significant compared to the non-saline ones but organic amendments have helped to improve the soil conditions and yield as observed at DHR site, India, and some sites in Sri Lanka, as confirmed from the farmer surveys.

Application of inorganic fertilizers alone increases GHG emissions. However, organic amendments seem to be the best option in improving salinity and farmers seem to have realized this, and the application of chemical fertilizers was minimum in most salinity-affected soils. Although rice-wheat and rice-fallow are the most common cultivation sequences in the IGP region, with respect to rice yield and GHG emissions, the best sequence is rice-fallow with organic amendments and appropriate irrigation practices.

Based on the findings for Sri Lanka, transplanting seedlings is the most effective way to minimize crop loss. Rearing nurseries in low salinity soil and then transplanting to saline-affected soil has been one of the sustainable BMPs. Of all the management combinations, the combination that had transplanting, the addition of organic matter, and intermittent irrigated water levels was identified as the BMP in terms of net GHG emissions and overall productivity (i.e. yield) and providing socio-economic benefits.

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Assessment of pastoral vulnerability and its impacts on socio-economy of herding community and formulation of adaptation options

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Adaptation strategy, life expectancy, livestock, pastoral vulnerability, socio-economy

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ABSTRACT

Rangelands located in arid and semi-arid regions are particularly vulnerable to climate change. The objective of this research project is to assess vulnerability and its impacts on socio-economy of pastoral society and to formulate adaptation options for the selected rangelands. The analysis process consisted of (1) using geospatial techniques to assess the pastoral vulnerability; (2) using statistical correlation analysis to assess the impact of vulnerability on the grazing societies' socio-economic conditions; (3) using qualitative document analysis (QDA) to evaluate policy documents; and (4) engaging in policy formulation, which included active participation by multiple academic researchers, policymakers, and representatives of the local community. The pastoral vulnerability assessment results reveal that drought, pasture usage and normalized difference vegetation index are the main drivers of vulnerability. Pastoral vulnerability increases the breeding stock's miscarriage rate and causes livestock loss, which may affect the socio-economics of the herder community, devaluing herders' labour and shortening their life expectancy. Two provinces' policies were reviewed, and the findings suggest that aligning development and sectoral policies with climate change responses (i.e. adaptation and mitigation) to enhance the adaptive and transformative capacity of rural communities is important. The adaptation options and policy recommendations for two provinces are identified to enhance the resilience of livelihoods to climate change to potentially reduce vulnerability to anthropogenic climate change and advance development.

HIGHLIGHTS

- Consecutive years of pastoral vulnerability resulted in lesser fat in the livestock and decreased ability to overcome disaster risks.
- Pastoral vulnerability strongly affected the female goats' miscarriage rate in the two provinces studied.
- Men in the Gobi-Altai province were more sensitive to pastoral vulnerability, which should be taken into account when considering future implications.
- Adaptation policies that integrate sustainable development and climate change mitigation are needed.

1. INTRODUCTION

1.1 Background

The socio-ecological system in a non-equilibrium environment is most vulnerable to changes in climate and land-use activities (Okuro, 2019). Nomadic pastoralism is a complex human-environmental system practised in Mongolia that includes livestock, grazing pastures, and a herding society, which are interdependent (Togtokh, Altanbagana, Davaanyam, Tserenchunt & Ojima, 2014). Traditionally, nomadic pastoralists have actively managed their use of grazing land to preserve ecosystem resources (Fernandez-Gimenez, Baival, Batjav & Ulambayar, 2015).

Mongolia is an agriculture-based country where pastoral livestock production contributes 10.52% of the country's GDP, uses 72.1% of its total land area, and employs 21.6% of its total workforce. The western region of Mongolia is a non-equilibrium environment (Illius & Connor, 1999), which is arid and experiences highly variable weather (Gomboluudev,2019). The social systems in these regions predominantly depend on pastoral grazing labour. As they typically employ traditional grazing strategies that are opportunistic and nomadic, risk reduction management and climate adaptation plans or strategies have not been officially formulated, which may lead to further environmental risks.

Vulnerability is defined as a combination of the degree of exposure (stressors) and sensitivity (Adger, 2006) of social-ecological systems under natural and human impacts and the adaptive capacity by mitigating and coping responses to new opportunities (Turner et al., 2003). Vulnerability to pastoralism in this study is explained through natural stressors of drought (Ojima, Togtokh, & Altanbagana, 2014), and human factors of pasture use and vegetation cover change as a set of linked impacts on social and economic conditions and coping strategies of herder communities in responding to these stresses.

Pastoral vulnerability causes a reduction in or loss of livelihood quality (Adger, 2006), economic productivity due to climate pressures (Troy, 2015) and over-grazing. Most of the studies of pastoral ecological vulnerability in Mongolia have focused on droughts or "dzud disasters" (Togtokh, Altanbagana, Ojima, & Suvdantsetseg, 2017; Natsagdorj, 2009; Reynolds et al., 2007). *Dzud* is a Mongolian term for severe winter weather and is associated with livestock deaths. Preventing dzud disasters is vital; however, the pastoral ecosystem's vulnerability is also an important issue (Shinoda, Nandintsetseg, & Erdenetsetseg, 2018). Instead, inadequate pasture and disaster risk management and the number of livestock animals (Nandintsetseg, Shinoda, Du & Munkhjargal, 2018), as well as aridity and precipitation levels during growing seasons, have the most significant impact on the regions' socio-ecological vulnerability.

Due to rapid increases in the number of livestock animals and climate change, the degradation of pasture land has increased to 70% (Asian Development Bank [ADB] & Ministry of Environment and Green Development [MED], 2014). The pasture yield has fallen by 20% to 30% in almost all regions in Mongolia and the pasture carrying capacity has dropped by 20%, further reducing the sustainability of nomadic animal husbandry (Bolortsetseg, Erdenetsetseg, & Bat-Oyun, 2002). Researchers studying climate change adaptation (Adger, 2006; Armitage, 2005) state that there is a need to consider linkages between ecosystem services supporting sustainable livelihoods in the local community through its primary products and services, and local communities' adaptive capability on the ecosystem. To effectively align adaptation policies and prioritize implementation measures, policymakers require comprehensive information obtained via vulnerability assessments of regions and various sectors (Preston, Yuen, & Westaway, 2011; O'Brien et al., 2004). To prevent the harm of pasture degradation induced by climate change and human activity, the assessment of pastoral grazing vulnerability and its impacts on the socio-economics of local communities and effective adaptive mechanisms are urgently needed. Therefore, adapting traditional pastoralism to address climate change in the vulnerable, arid regions is challenging, but it is important for sustainable pasture use, pasture management planning, and the effective implementation of adaptive measures.

1.2 Objectives

The main objective of this research project is to assess pastoral socio-ecological vulnerability and formulate adaptation strategies for the selected regions' grazing societies using a participatory approach. The specific goals are as follows:

- assess the pastoral ecological vulnerability of the two case areas;
- assess the impact of vulnerability for socio-economics of grazing society;
- evaluate current policy documents; and
- formulate adaptation strategies.

2. METHODOLOGY

2.1 Research area

The two nomadic pastoralism-based provinces selected for the study are Gobi-Altai and Khovd, which are located in western Mongolia. These areas are most affected by climate change-related disasters, such as dzud (Davaadorj, Erdenetsetseg, Elbegjargal, & Oyunjargal, 2017), and drought (Batnasan, 2003). They have a highly vulnerable ecosystem and the largest percentage of out-migration, and have undergone significant cultural changes while attempting to retain the regions' nomadic rangeland systems, which are adversely affected by overgrazing in the Gobi Desert ecological region (Suvdantsetseg, Oba, Yan, & Myagmarsuren, 2017).

Gobi-Altai province is the second-largest province in Mongolia in terms of territory; it covers a total area of 141,100 km^2, and the elevation ranges from 1,000–3,802 m above sea level. The annual average precipitation is 80–135 mm, and most of the rainfall occurs during the summer season. This province consists of 18 administrative units (*soums*) and about 3.5 million sheltered livestock (NSOM, 2018). The livestock sector generates 43.8% of the province's GDP. By 2018, the population had reached 58,400, decreasing by 18.4% since 1998, and 21% of the total population are herders, totalling 16,711 householders, 66.6% of whom live in rural areas and practice nomadic herding.

Khovd province covers a 76,100 km^2 area lying in Mongolia's Altai mountain range and Great Lakes Depression, where the altitude ranges from 1000–4200 m. The annual average precipitation is 50–300 mm, and the annual average air temperature is −0.3°C. This province has a population of 87,300 people, which has decreased by 3.8% since 1998; 74% of the rural population in 16 soums are living in grazing areas, and 26% of them live in soum (town) centres (NSOM, 2018). Most (67%) of the land is used for agriculture (Munkhdulam, Avirmed, Jonathan & Renchinmyadag, 2018), pasturing about 6.8 million livestock and generating 36.9% of Mongolia's GDP.

2.2 Data sources used

This project used statistical, observational, meteorological, field survey, and remote sensing data covering the period of 1998–2017, collected from various sources. A brief description of the data is provided in Table 1. Our two teams collected the field survey data during field visits. One of the field surveys was performed in two sub-provinces from 16 July 2018 to 5 August 2018, which were selected because they are most vulnerable in terms of pasture degradation based on an initial pasture ecological vulnerability assessment of two provinces. Based on the research results, the collaborators decided to identify the main reasons and conditions of the grassland changes, including changes in vegetation types and the degradation of grassland biomass and volumes, by comparing field survey and map data collected in 1981 and 2018. The qualitative data were collected during field visits conducted from 19–29 July 2019 via focus group discussions for policy-scenario development purposes. The reviewed policy documents were obtained from local government offices in the two provinces.

2.3 Methods

The general framework of the project applied a combination of geo-visualization techniques and a participatory approach for all levels of data collection, integrating method development and assessment, as well as policy-scenario development during group meetings, training and discussion workshops, and documents review. The analysis process consisted of (1) using geospatial techniques to assess the pastoral vulnerability; (2) using statistical correlation analysis to assess the impact of vulnerability on the grazing societies' socio-economic conditions; (3) using qualitative document analysis (QDA) to evaluate policy documents; and (4) engaging in policy formulation, which included active participation by multiple academic researchers, policymakers, and residents of the local community.

2.3.1 Assessment of pastoral vulnerability

The socio-ecological vulnerability assessment (Togtokh, Altanbagana, Ojima, & Suvdantsetseg, 2017) was modified for use in the ecological vulnerability assessment of pasture lands (Equation 1). Multivariate statistical analysis (Hidalgo & Goodman, 2013), as well as weighted summation analysis for rescaling different index values, were applied to the data. The main driving measures of pastoral vulnerability were identified as drought, pasture use, and normalized difference vegetation index (NDVI); see Equation 1 below:

$$V_{t,i}^{eco} = \frac{\frac{\Delta S_{t,i}^{norm} + \Delta N_{t,i}^{norm}}{2} + Vg_{t,i}^{norm}}{2} \qquad (1)$$

Here, $V_{t,i}^{eco}$ is pastoral vulnerability, while $\Delta S_{t,i}^{norm}$ refers to the normalized drought index, $\Delta N_{t,i}^{norm}$ refers to the normalized pasture use index, and $Vg_{t,i}^{norm}$ refers to the normalized difference vegetation index.

The drought index was calculated using the Ped's index, which represents climate variability (Natsagdorj, 2009). The pasture lands' carrying capacity, which was determined at the soum level by the Mongolian government (Mongolian Academy of Sciences, 1990), was used for the threshold value of pasture use. Pasture use index (Tserendash & Bilegt, 2017) was modified to calculate the pasture use for the pastoral vulnerability assessment. The NDVI indicates the density of green vegetation (Weier &

Statistical					
No	Name of data	Time range	Units	Spatial range	Source
1.	Livestock	1998-2017	Number	All soums	NSOM
2.	Livestock by type	1998-2017	Number	All soums	NSOM
3.	Livestock loss by type	1998-2018	Number	All soums	NSOM
4.	Barren female animals by type	1998-2018	Number	All soums	NSOM
5.	Miscarriage female animals by type	1998-2018	Number	All soums	NSOM
6.	Breeding stock by type	1999-2018	Number	All soums	NSOM
7.	Migration	1990-2018	Number	Province	NSOM
8.	Poverty rate	2010	Percentage	All soums	NSOM
9.	Life expectancy	1998-2017	Number	Province	NSOM
10.	Well	2012, 2015, 2018	Number	All soums	NSOM
11.	Cereals	2000-2018	Ton	All soums	NSOM
12.	Potatoes	2000-2018	Ton	All soums	NSOM
13.	Vegetables	2000-2018	Ton	All soums	NSOM
14.	Fodder crops	2000-2018	Ton	All soums	NSOM
15.	Insured livestock	2010-2018	Number	All soums	NSOM
16.	Insured households	2010-2018	Number	All soums	NSOM
17.	Bank loan	2010-2018	Tugrug	All soums	NSOM
18.	Bank deposit	2010-2018	Tugrug	All soums	NSOM
19.	Herder household	2012-2018	Number	All soums	NSOM

Meteorological observation					
No	Name of data	Time range	Units	Spatial range	Source
1.	Annual temperature	1970-2017 Monthly	Celsius	All soums	NAMEM
2.	Precipitation	1970-2017 Monthly	Mm	All soums	NAMEM
3.	Pastoral area	1990	Hectare	All soums	NAM
4.	Pasture carrying capacity	1990	Sheep/per hectare	All soums	NAM

Raster						
No	Satellite name	Product name	Time range	Units	Spatial range	Source
1.	SPOT VEGE	NDVI data 2nd ten days of August	1998-2000	1 km	2 provinces	https://earthexplorer.usgs.gov/
2.	eMODIS	NDVI data 2nd ten days of August	2001-2017	250 m	2 provinces	https://earthexplorer.usgs.gov/

Field survey						
No	Name of data	Date	Unit	Number of sites	Sampling size	Collected site
1.	Biomass data	16 July to 5 August 2018	Hectare	103	1m x1m	Chandmani & Biger

Document reviewed				
No	Name of data	Implementation period	Policy area	Implementing area
1.	Comprehensive development policy	2012-2020	Development	Gobi-Altai province
2.	Governor's Action Program	2016-2020	Development	Gobi-Altai province
3.	Pasture management program	2012-2020	Land & Environment	Gobi-Altai province
4.	Sub-program to combat desertification	2012-2020	Land & Environment	Gobi-Altai province
5.	Environmental master plan	2012-2020	Land & Environment	Gobi-Altai province
6.	Development strategy	2015-2020	Development	Khovd province
7.	Green development policy	2016-2026	Development	Khovd province
8.	Governor's Action Program	2016-2020	Development	Khovd province
9.	Pasture use improvement program	2016-2020	Land & Environment	Khovd province

TABLE 1. Brief description of data used for selected areas. NSOM: National Statistics Office of Mongolia; NAMEM: National Agency of Meteorological and Environmental Monitoring; NAM: National Atlas of Mongolia. * The five types of livestock are horse, cattle, camels, sheep and goats.

Herring, 2000) and the biomass of vegetation changes (Miyasaka, Okura, Zhao, & Takeuchi, 2016). NDVI values, by themselves, do not provide sufficient information to conduct a pastoral vulnerability assessment. Therefore, we considered both multiyear average NDVI values and the coefficient of the linear trend equation of NDVI changes for the last 20 years to express trends in vegetation changes. Alternatively, the degraded grazing area was calculated to determine whether it exceeded the threshold value of vegetation vulnerability for each pixel. The threshold value of vegetation vulnerability was selected by the difference of the mean value and the standard deviation in the biomass peak time data derived from satellite images from 1999–2017 and determined for each pixel. Based on the results of this analysis, we selected two sub-provinces (Biger in Gobi-Altai province and Chandmani in Khovd province) for the detailed pasture change and vegetation surveys.

The threshold values of each indicator were applied to determine pastoral vulnerability in the case areas. Variables exceeding the threshold value were assumed to be the baseline for pastoral vulnerability. To combine individual indicators into an integrated pastoral vulnerability index, variables were calculated into the same range, from 0.0–1.0, by rescaling the weighted summation of values for long-term data.

2.3.2 Correlation analysis of pastoral vulnerability on socio-economics of grazing society

In this part of the study, we assessed the impacts of pastoral vulnerability on the socio-economic variables of selected pastoral communities. When examining a pastoral socio-ecological system, it is important to examine how pastoral ecosystem is vulnerable to human- and climate-induced change, including which areas are most affected and which indicators are more sensitive to the effects on the herders' socio-economic condition. Pearson correlation analysis (Lane, 2019) was applied to measure the strength of the relationships among variables. We performed a correlation analysis using 19 social, economic, and environmental indicators. The most significant results of this analysis, miscarriage rates among breeding stock in the livestock sector, and human life expectancy in the pastoral society are discussed in this paper.

2.3.3 Evaluation of policy documents

This part of the study used QDA to understand the extent to which the policy documents of two provinces, Khovd and Gobi-Altai, incorporate climate change and sustainable development giving an emphasis on pastoral societies and livestock sector. The QDA process uses subjective scoring, and we ensured consistency by following specific steps to perform an in-depth analysis: (i) collecting documents, (ii) identifying the main areas of analysis, (iii) coding the documents, and (iv) analysing findings. The synergy informed the building blocks for the QDA of climate change adaptation, mitigation responses, and sustainable development (Nhuan, 2019): climate adaptation, mitigation, and transforming capacity. Appropriate indicators for the building blocks were selected based on the SDGs aligned with Mongolia's National Green Development Policy and Sustainable Development Vision 2030 (SDV). For climate adaptation in terms of social resilience, the indicators included income diversification and poverty reduction (SDG 1), health and wellbeing of pastoral societies (SDG 3), water and sanitation including sustainable water management (SDG 6), and full and productive employment that are connected to pastoral livestock-keeping and sustainable tourism development (SDG 8). Other indicators of adaptation in terms of enhancing natural resilience included the sustainable land and pasture management and protection of pastoral ecosystems, combating desertification, and biodiversity conservation (SDG 15). Indicators of mitigation included reducing GHG emissions and encouraging renewable energy (SDG 7). For transforming capacity, we adopted indicators such as quality education and vocational skill development for herders (SDG 4), improved infrastructure including road networks to have access to markets and enabling services (SDG 9), and capacity building on adaptation to climate change, natural disaster and risk prevention (SDG 13).

A scoring system was developed based on the work of Gouais and Wach (2013) (Table 2). To determine the extent to which the policy documents align with the "building blocks", each of the policy documents was analysed separately. All assessments of alignment were supported by explanations and quotes from the policy to ensure rationale for each assessment.

2.3.4 Development of policy recommendations

After the three parts assessment, we organized several group meetings with academic researchers and collaborators, as well as three focus group meetings and two workshops that included multi-stakeholders from herding groups, academics, civil societies, and local, provincial, and national governors. The group meetings aimed to identify the key indicators of pastoral vulnerability, main factors affecting the herding communities, major barriers to adaptation and the lack of strategies to address them in the policy documents, and ways to successfully resolve these issues from the academic perspective. In these meetings, all of our research collaborators participated and presented findings and outputs of research via the Internet and face-to-face. Three

Type of alignment	*Description of alignment*	*Score*
High alignment	The policy aligns strongly with the indicators of adaptation, mitigation and transforming capacity (A/M/Tc). Policy devotes attention to the particular building block and includes specific activities for achieving the particular block.	3
Partial alignment	Although the policy supports the various indicators of A/M/Tc, it is less clear in terms of how the indicators and each particular building block could be achieved. There is limited evidence present of how the specific indicators as well as the building blocks could be achieved in practice.	2
Limited alignment	The policy supports a particular indicator of the A/M/Tc building block but there is a lack of evidence to support alignment with it.	1
No alignment	There is no evidence in the document to suggest that the policy supports the implementation of the building block or even encourages it.	0

TABLE 2. Scoring criteria for alignment of the policy documents with the building blocks (modified from Gouais & Wach, 2013)

participatory focus group discussions were organized in the local project areas (the Biger soum and province center of Gobi-Altai province and the Zereg soum of Khovd province) from 19–30 July 2019. The group discussions covered various issues, including increasing pasture land degradation from the locals' viewpoint and lived experiences, the visible impacts of pastoral vulnerability on their livelihoods, and barriers to formulating and implementing policy documents. Finally, a participatory workshop entitled the 2nd Workshop on Socio-ecological Systems Governance for Sustainability was organized in Ulaanbaatar, Mongolia, from 23–24 August 2019 to conclude this part of the research and discuss policy recommendations.

3. RESULTS AND DISCUSSION

3.1 Pastoral vulnerability analysis

Two case areas' levels of pastoral vulnerability over the past two decades are presented in Figure 1. On the map, base colours reflect the level of pastoral vulnerability, and the graph shows the average value of components in each soum over the past two decades. The level of pastoral vulnerability in the two case areas is influenced by each of the three indicator values; the variable with the most significant impact is drought, followed by pasture use. Four soums in Gobi-Altai (Figure 1a) and five soums in Khovd (Figure 1b) were found to have the highest level of pastoral vulnerability based on climate- and human activity-related impacts.

Table 3 presents the two case areas' level of vulnerability (i.e. high, moderate, and low) using three indicators: humans, livestock, and pasture area. Khovd province is at a high level of risk for people and livestock being affected, where human-related activities are the main driving forces in pastoral vulnerability. In Gobi-Altai province, climate change-related impacts are the main driving factors in pastoral vulnerability.

3.2 Correlation analysis of pastoral vulnerability on the herding communities' socio-economic conditions

3.2.1 Livestock sector

Pastoral vulnerability is a key factor in increased livestock miscarriage and loss, which may negatively impact the herders' income. Dzud is one of the main

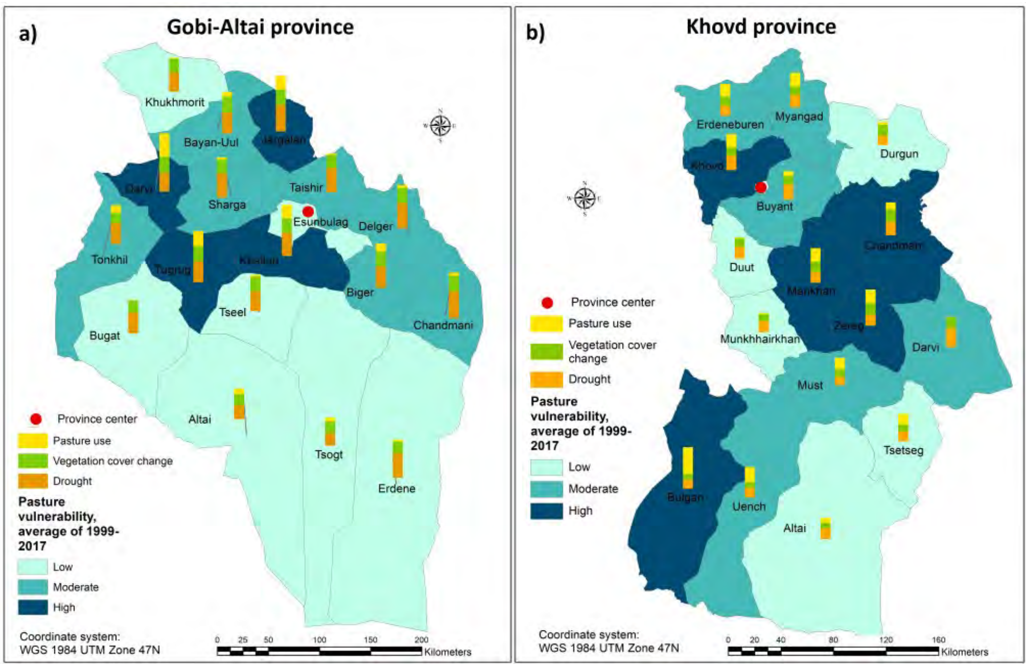

FIGURE 1. The pastoral vulnerability is high in mountain steppe region in Gobi-Altai province and desert and desert steppe regions in Khovd province. Main driving component indicators are climate-related drought in Gobi-Altai province and human- related pasture use in Khovd province.

Vulnerability level	*Gobi-Altai*			*Khovd*		
	People %	*Livestock %*	*Pasture area %*	*People %*	*Livestock %*	*Pasture area %*
High	14	20.8	12.6	27.6	35.1	31.5
Moderate	28.4	39.8	26.8	56.8	23.7	33.4
Low	57.5	39.4	60.6	15.5	41.2	35.1

TABLE 3. Results of the ecological vulnerability assessment.

causes of livestock loss (Natsagdorj, 2009), but its impact is lower when compared to pastoral vulnerability. Livestock miscarriage and loss increased in the winter and spring months following years with high pastoral vulnerability (Figures 2a and 2b). High pastoral vulnerability for 2–3 consecutive years leads to insufficient fat intake in the livestock animals' diets during the summer months, negatively impacting their ability to survive during the upcoming cold winter months and, ultimately, increasing their mortality rates. In the years with low pastoral vulnerability, the number of livestock animals increased rapidly (Figure 2).

Statistical correlations were calculated for pastoral vulnerability and the miscarriage rate among breeding stock for four types of female animals (Table 4). High miscarriage rates devalue the herders' labour and reduce their income. In Gobi-Altai and Khovd provinces, 86%–98% and 83%–93%, respectively, of the total livestock are small animals (i.e. sheep and goats); goats comprise 45%–76% of the total herd in Gobi-Altai and 37%–66% in Khovd province. The small livestock animals' miscarriage rates were more susceptible to pastoral vulnerability and were strongly correlated with female goats' miscarriage rates in the two provinces. However, no strong correlations were found for other herd types.

3.2.2 *Life expectancy of rural communities*

Over 18 years (2000–2018), the life expectancy of Gobi-Altai province's residents reached the national average, while in Khovd province, it surpassed the national average (Figure 3). In 2000, women lived on average 5 years longer than men in Gobi-Altai, and 6 years longer than men in Khovd province. In 2018, the difference was 9 years in Gobi-Altai and 6 years in Khovd. The average life expectancy of men living in Gobi-Altai increased by 5 years over the same period (2000–2018), while that of women increased by 10 years (Figure 3a); however, in Khovd province, the difference in life expectancy for men and women remained stable at 6 years (Figure 3b). These findings may be due to some lifestyle factors, such as living and working conditions and local cultural differences. Male herders are more affected by pastoral activities due to their working conditions in a harsh climate and the limited services provided by social systems in Gobi-Altai province. In 2008, the average life expectancy of men decreased from 61 to 59 compared to the previous year, while it dropped from 68 to 67 for their counterparts in Gobi-Altai. As for Khovd province, differences in life expectancy decreased for both groups, from 64 to 61 for men and from 71 to 70 for women. These numbers suggest that men are more sensitive to pastoral vulnerability. This result is an important issue, especially

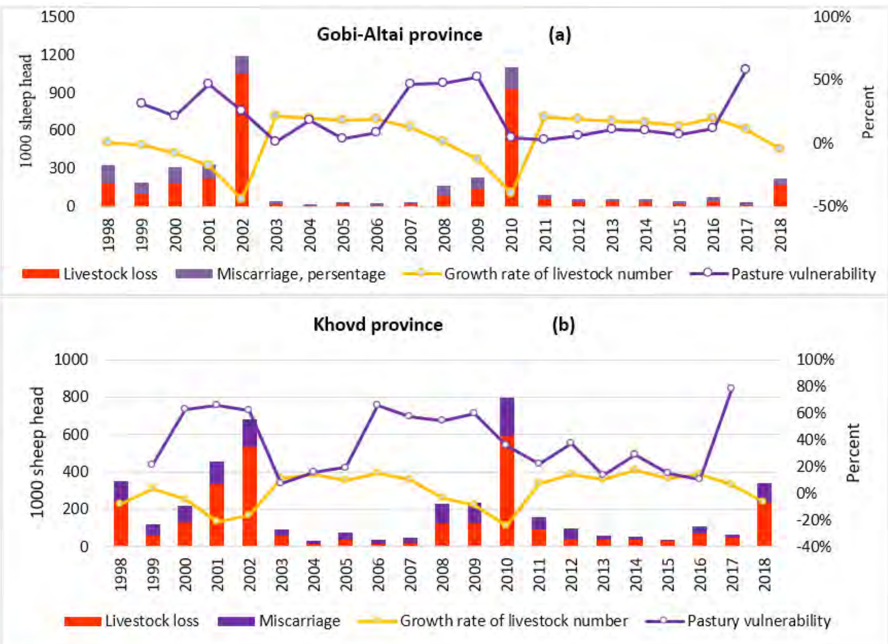

FIGURE 2. High pastoral vulnerability results in increased livestock miscarriage and loss, and decreased livestock growth rate.

Gobi-Altai province	*Mare*	*Cows*	*Female sheep*	*Female goats*	*Khovd province*	*Mare*	*Cows*	*Female sheep*	*Female goats*
Delger	0.29	0.47	0.41	0.28	Darvi	-0.05	0.10	-0.05	0.81
Taishir	0.08	0.29	0.10	0.34	Altai	0.67	0.53	0.29	0.69
Tugrug	0.17	0.43	0.27	0.37	Zereg	0.37	-0.05	0.13	0.67
Chandmana	0.50	0.26	0.49	0.50	Chandmani	0.34	0.16	0.37	0.65
Khukhmorit	0.36	0.32	0.39	0.51	Munkhkhairkhan	0.20	0.41	0.64	0.61
Esunbulag	0.50	0.13	0.63	0.53	Bulgan	0.34	0.28	0.29	0.61
Altai	0.29	0.56	0.55	0.56	Mankhan	0.23	0.22	0.40	0.56
Dariv	0.40	0.46	0.30	0.57	Must	0.27	0.20	0.22	0.50
Khaliun	0.17	0.46	0.51	0.60	Tsetseg	0.69	0.52	0.17	0.46
Biger	0.29	0.34	0.36	0.61	Durgun	0.40	0.38	0.41	0.40
Jargalan	0.24	0.57	0.57	0.61	Khovd	0.22	0.07	0.13	0.37
Tsogt	0.52	0.36	0.49	0.64	Myangad	-0.12	0.23	0.41	0.33
Bayan-Uul	0.07	0.25	0.37	0.68	Duut	-0.16	0.16	0.19	0.27
Sharga	-0.04	0.31	0.58	0.68	Buyan	0.03	0.14	0.21	0.26
Erdene	0.45	0.47	0.58	0.69	Uench	0.04	0.35	0.11	0.26
Tonkhil	0.35	0.17	0.57	0.72	Erdeneburen	-0.02	0.10	0.66	0.13
Tseel	0.30	0.33	0.29	0.74					
Bugat	0.29	0.62	0.74	0.86					

TABLE 4. Correlation analysis of pastoral vulnerability and livestock miscarriage rates among different types of livestock in the two selected areas.

in Gobi-Altai province, as well as at the national level in terms of pension system policies related to men.

3.3 Assessment of policy documents

This part of the study assessed the extent to which policies in the economic development and environmental sectors align with climate change response (i.e. adaptation and mitigation) and sustainable development goals and identified varying levels of coherence amongst these policies in Gobi-Altai and Khovd provinces. After applying qualitative document analysis and content analysis to the policy documents, the findings suggest that the policies of these two provinces acknowledge climate change as a threat to the development in the western region.

In Gobi-Altai province, all the reviewed policies have "limited alignment" with climate change responses, particularly the inadequate adaptation measures adopted to strengthen social resilience. It implies that people are not well prepared for future changes, and the capacity remains low for dealing with adverse climate and environmental impacts. Gobi-Altai province has not updated its midterm development policy, or comprehensive development policy (CDP), under global SDGs and SDV-2030, and Mongolia's green development policy. This finding has implications for the province as it needs to formulate new policies to align climate change adaptation and sustainable development.

In Khovd province, the reviewed policy documents have "partial" and "limited alignment" as these contain climate change responses with good adaptation measures directed at enhancing natural resilience. Khovd province has developed and approved its midterm policies, provincial development strategy (DS), and green development policy (GrDP) following the new national policies. In Khovd province, human impacts, including the increased number of livestock animals, are equally important for pasture ecological vulnerability, requiring comprehensive policy measures directed at reducing pastoral vulnerability and promoting sustainable development.

The analysis of two provinces' policy documents indicates there is a need for well-aligned adaptation policies to enhance the resilience of their residents' livelihoods to climate change because climate change is seen as a development issue, and adaptation activities can potentially reduce vulnerability to climate and other variability and can advance economic development.

3.4 Adaptation options

A final workshop was organized from 23–24 August 2019 at the Mongolian Academy of Sciences in Ulaanbaatar to conclude the research outputs and identify potential adaptation options to reduce pastoral vulnerability in the selected areas. The participants included academic research members from all collaborating

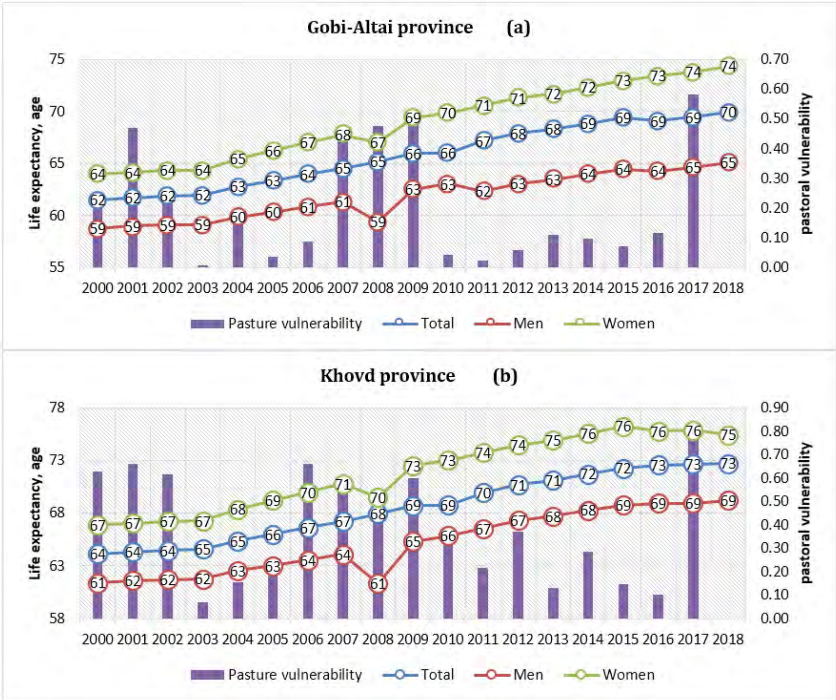

FIGURE 3. Difference of life expectancy for women and men in Gobi-Altai province is increasing but in Khovd province it is decreasing.

countries, herders, soum and provincial government officers, and civil societies from the two case areas and other experts from national advisory groups. During the workshop, the results of academic studies of pastoral vulnerability, socio-economic impacts, and the policy document review, as well as land degradation processes and the adaptation experiences of Chinese and Japanese team members, were presented before conducting a group discussion. Based on the research outputs and experiences of local participants, ways to resolve issues were discussed, and suitable adaptation options were identified and mapped for each soum in the Govi-Altai province (Figure 4a) and Khovd province (Figure 4b). The following general adaptation options are expected to be useful to reduce pastoral vulnerability in the case areas:

» Establish a pasture degradation inventory and monitoring system for future prevention and measurable database
» Identify areas experiencing drinking water contamination for human and groundwater depletion for livestock and biodiversity in current and future conditions
» Protect pasture degradation from steppe mice, grasshoppers and other rodents
» Improve health services for herding communities taking into consideration men's living and working conditions for their life expectancy
» Establish a herders' capacity development system through adaptive technologies and latest information

4. CONCLUSION

The collaborative project has enabled the participation of several regional and local governments and communities, as well as multiple academic teams; applied geospatial tools to assess climate change within collaborative processes and assess pastoral vulnerability; conducted correlation analyses of variables related to the socio-economics of pastoral societies; and evaluated policy documents and policy formulations developed through the active participation of multiple stakeholders. Pastoral vulnerability was assessed by evaluating key factors developed by the team and analyzed the relevance of factors in the socio-economic conditions of two grazing societies over the past 20 years in the selected areas of western Mongolia. The most significant variable was climate change-related drought, followed by intensive pasture use in the case areas. The study's findings reveal that pastoral vulnerability results in increased miscarriage rates in female goats, which is reflected in high correlation values of 0.5–0.8. In terms of rural communities at both provinces, differences in life expectancy for men and women are high in Gobi-Altai, suggesting further detailed studies and policies are needed to address the working conditions of herders impacted by climate change and their potential social service needs. The analysis of the two provinces' policy documents indicates the need for more closely aligned adaptation policies for climate change and sustainable development goals to enhance livelihood resilience in the face of climate and other variabilities. The flexibility

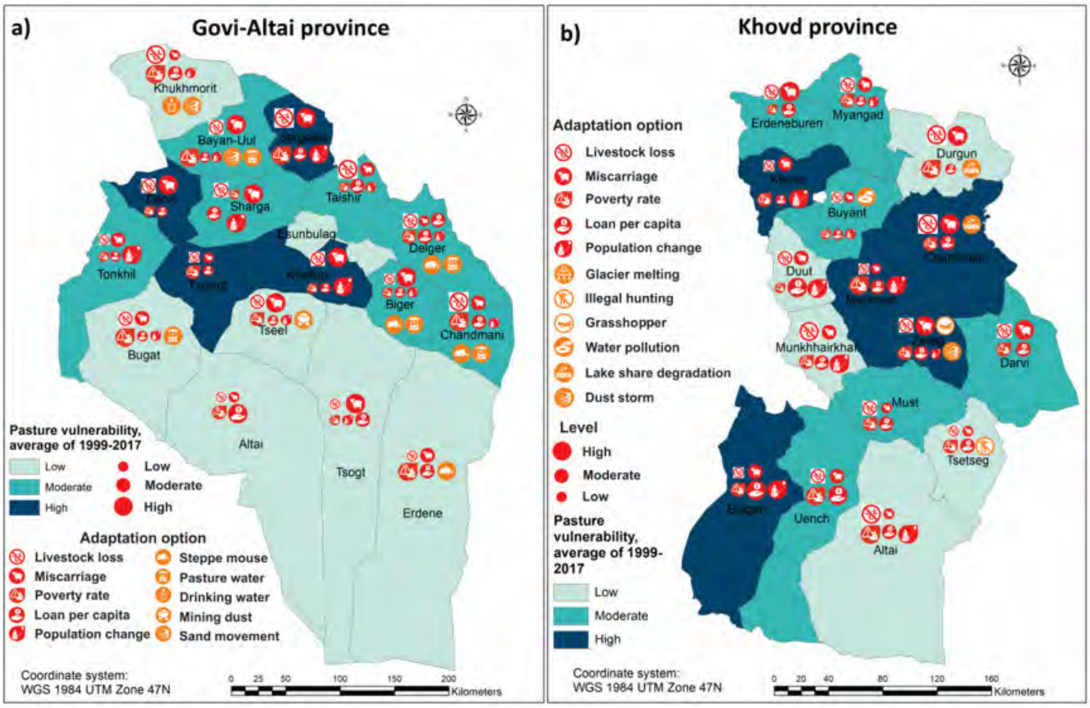

FIGURE 4. Adaptation options for reduction of pastoral vulnerability by social, ecological and economic aspects in each soum of Gobi-Altai and Khovd provinces, Mongolia.

of the local pastoral adaptation strategy process has allowed the application of geo-visualizations in place-based problem-solving and decision-making processes in a specific sociopolitical context of municipal and regional governments.

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Consumers' risk perception of vegetables in Southeast Asia: Evidence from Laos, Cambodia, and Viet Nam

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ABSTRACT

Vegetable safety is a public concern in Laos, Cambodia, and Viet Nam—developing countries in Southeast Asia. Eliminating this concern requires insight into factors shaping it. Food risk perception might differ among countries due to the dissimilarities in culture, social, and economic conditions. However, an understanding on this difference is lacking in Southeast Asia. This paper is the first attempt to compare factors influencing risk perception of vegetables in Laos, Cambodia, and Viet Nam. Principle component analysis and ordered logit regression were employed on a sample of 1,199 consumers from the three countries. We found trust and perception of hazards influence risk perception across countries. Gender shaped risk perception in Laos and Viet Nam. The importance of vegetables and risk information determines risk perception in Viet Nam only, while hazard knowledge and homegrown vegetables are found to be predictors of risk perception solely in Cambodia. Since Laos, Cambodia, and Viet Nam are inhomogeneous in risk perception, policy measures to address food risk perception should be tailored to each country.

KEYWORDS

Determinants, developing countries, food safety, risk perception, Southeast Asia, vegetables

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HIGHLIGHTS

- Risk perception of vegetables was considerably high and varies across Laos, Cambodia, and Viet Nam.
- Trust and perception of hazards determine risk perception in all selected countries.
- Other factors influencing risk perception differed among the three countries.
- Interventions to address heightened food risk perception should be tailored to each country.

1. INTRODUCTION

The prevalence of food-borne outbreaks has drawn attention to food safety issues in Southeast Asia. In this region, food-borne illnesses have caused sickness in 150 million people and death in 175 thousand people, which occupied about 42% of the global death toll (World Health Organization [WHO], 2015). Food safety is even more problematic in Laos, Cambodia, and Viet Nam, and which are considered developing countries in Southeast Asia. This is due to the lack of food safety knowledge along food chains, limited resources for food safety surveillance, and poor enforcement of regulations. Subsequently, consumers in these countries are very concerned about food safety (Chadwick, Otte, & Roland-Holst, 2008, World Bank, 2017). Food safety concerns reflect low consumer confidence in food, which might lead to negative societal and economic effects in Laos, Cambodia, and Viet Nam. In order to solve the problem, it is important to gain insight into consumer self-assessment of food safety risk.

This paper focuses on risk perception of vegetables in Laos, Cambodia, and Viet Nam. Risk perception of vegetables is a subjective evaluation of the health risk associated with contaminated vegetables. Among different contamination sources of vegetables, pesticide residue is the biggest challenge in these countries, as there is ample evidence of pesticide overuse in vegetable production (Schreinemachers et al., 2017). Since studies on risk perception of food, including vegetables, are scant in Laos and Cambodia, it is unclear how Laotians and Cambodians perceive vegetable risk. Some surveys in Viet Nam show that consumers rate vegetables as the riskiest common food due to concerns about pesticide residue (Ha, Shakur, & Pham Do, 2019, Figuié, Bricas, Thanh, Truyen, & de l'Alimentation, 2004). Besides hazard concerns, little is known about other factors influencing risk perception of vegetables. This paper will address these research gaps.

The objective of this paper is to compare the determinants of vegetable risk perception among Laos, Cambodia, and Viet Nam. Previous literature has established some key predictors of food risk perception. Individuals tend to lower risk perception when they trust in institutions (Hobbs & Goddard, 2015) and feel that they

Variables	**Whole sample** *(n=1199)*			**Laos** *(n=328)*		**Cambodia** *(n=300)*		**Vietnam** *(n=571)*	
	Mean	*SD*	*[Min-Max]*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Vegetable Risk Perception	3.56	0.90	[1-5]	3.43[a]	0.91	3.41[a]	0.81	3.72[b]	0.93
Hazard Knowledge									
- Pesticide	2.75	1.16	[1-5]	3.25[a]	1.15	2.01[b]	0.96	2.85[c]	1.06
- Bacteria	2.61	1.06	[1-5]	2.95[a]	1.00	2.02[b]	0.88	2.74[c]	1.06
- Heavy metal	2.17	1.14	[1-5]	2.71[a]	1.21	1.32[b]	0.64	2.31[c]	1.06
- GMO	1.93	1.04	[1-5]	2.25[a]	1.07	1.38[b]	0.65	2.04[c]	1.08
Hazard Perception									
- Pesticide	3.98	0.86	[1-5]	3.96[a]	0.84	3.92[a]	0.65	4.02[a]	0.97
- Bacteria	3.64	0.91	[1-5]	3.48[a]	0.81	3.48[a]	0.78	3.82[b]	0.99
- Heavy metal	3.75	0.95	[1-5]	3.40[a]	0.87	3.61[b]	0.75	4.02[c]	1.01
- GMO	3.54	1.08	[1-5]	3.18[a]	0.92	3.46[b]	0.91	3.78[c]	1.18
Risk Information									
- TV	3.20	1.05	[1-5]	3.03[a]	0.97	2.55[b]	0.88	3.65[c]	0.97
- Social media	3.22	1.26	[1-5]	3.32[a]	1.34	2.64[b]	1.11	3.48[a]	1.20
- Word of mouth	3.11	1.07	[1-5]	2.85[a]	1.03	3.07[b]	1.03	3.29[c]	1.09
Institutional Trust									
- Farmer	2.25	0.90	[1-5]	2.64[a]	0.83	2.64[a]	0.70	1.83[b]	0.97
- Retailer	2.25	0.94	[1-5]	2.57[a]	0.77	2.14[b]	0.65	2.14[b]	1.11
- Government	2.93	0.93	[1-5]	3.44[a]	0.79	2.76[b]	0.83	2.40[c]	1.26
Children[1]	1.01	1.01	[0-6]	1.13[a]	1.03	1.12[a]	1.14	0.87[b]	0.91
Age	39.54	13.08	[18-78]	43.96[a]	11.80	42.55[a]	13.50	35.42[b]	12.28
Education[2]	2.62	1.46	[0-6]	2.18[a]	1.34	1.44[b]	1.17	3.49[c]	1.06
Gender[3]	0.21	0.43	[0-1]	0.33[a]	0.47	0.07[b]	0.26	0.21[c]	0.41
LogIncome[4]	2.46	0.29	[0.9-3.7]	2.39[a]	0.28	2.51[b]	0.27	2.47[c]	0.29
Vegetable Importance[5]	4.08	0.80	[1-5]	3.95[a]	0.75	4.11[b]	0.53	4.14[b]	0.92
Vegetable Poisoning[6]	0.52	1.55	[0-1]	0.36[a]	1.08	0.82[b]	2.61	0.44[a]	0.88
Home grown[7]	0.55	0.5	[0-1]	0.77[a]	0.42	0.40[b]	0.49	0.50[b]	0.50

TABLE 1. Descriptive statistics of selected variables.

Note: a,b,c: different superscripts denote statistically different mean scores at 5% level using ANOVA analysis and Tukey's post hoc test. 1: number of children; 2: education level is from 1 (no schooling) to 6 (postgraduate); 3: gender = 1 if male; 4: logarithmic monthly income in USD; 5: perception of the importance of vegetables in the diet; 6: number of times the respondent has experienced vegetable poisoning in the last 2 years; 7: homegrown = 1 if the household is growing vegetables.

are knowledgeable about food hazards (Siegrist, 2000). In contrast, perception of the danger of food hazards (Cheng et al., 2016) and information about food incidents (Wachinger, Renn, Begg, & Kuhlicke, 2013) increase risk perception. According to Douglas and Wildavsky (1983), risk perception was a social or cultural construct. Laos, Cambodia, and Viet Nam are different in regards to food safety management, economic development, and social and cultural settings. Risk perception of vegetables and its determinants, therefore, might vary among these countries. This paper is the first cross-country analysis of food safety risk perception in Asian developing countries. The paper will advance our understanding of food risk perception and provide evidence-based solutions to address food safety concerns in Asian developing countries.

2. METHODOLOGY

The study used data from our consumer survey conducted in Laos, Cambodia, and Viet Nam in 2019. The survey was conducted in six large cities including Vientiane and Savannakhet (Laos), Phnom Penh and Siem Reap (Cambodia), and Hanoi and Ho Chi Minh City (Viet Nam). A total of 1,199 main food shoppers comprising of 571 Vietnamese, 328 Laotians, and 300 Cambodians were randomly surveyed in the mentioned cities.

Table 1 shows the dependent variables and their potential explanators that have been well established in previous literature. Vegetable Risk Perception, the dependent variables were originally measured by a 5-point Likert scale. It was then transformed into a 3-point scale: 1 (low risk), 2 (medium risk), and 3 (high risk) for better interpretation of regressions. We employed ordered logit regression that is suitable for ordinal variables. Our survey revealed a high level of vegetable risk perception in the surveyed countries, particularly in Viet Nam (mean score of 3.56 for the whole sample, of 3.7 for Viet Nam, Table 1).

Hazard Knowledge (self-reported knowledge of hazards), Hazard Perception (perception about the danger of hazards), Risk Information (information acquisition about food incidents), and Trust are constructs that were measured by 14 items in total. Some correlation coefficients of these items were in the range from 0.5 to 0.7. Hence, Principle Component Analysis (PCA) was employed to transform this 14-item dataset into fewer uncorrelated components that preserve most of the information of the dataset (Jolliffe, 2002). ANOVA analysis shows that most of the mean scores of the items were statistically significantly different among Laos, Cambodia, and Viet Nam (Table 1). This suggests that the datasets of selected countries were inhomogeneous.

	Laos				*Cambodia*				*Viet Nam*			
1. Knowledge of hazards	1	2	3	4	1	2	3	4	1	2	3	4
Pesticide	.802				.742				.819			
Bacterial	.854				.789				.844			
Heavy metal	.772				.853				.859			
GMO	.772				.737				.768			
2. Perception of hazards												
Pesticide		.674				.629				.786		
Bacterial		.762				.750				.858		
Heavy metal		.746				.836				.900		
GMO		.739				.848				.764		
3. Trust												
Farmer			.782				.821				.761	
Food retailer			.817				.756				.693	
Government			.665				.715				.764	
4. Risk Information												
TV				.782				.704				.693
Internet				.416				.791				.732
Word of mouth				.657				.626				.745
Total variance explained (%)	58.148				64.092				63.773			
KMO value	0.663				0.726				0.717			

TABLE 2. PCA results. Note: The rotation method is Varimax with Kaiser Normalization.

PCA, therefore, was applied separately for each country. Components retained from PCA must have eigenvalue that is equal to, or larger than 1 (Jolliffe, 2002). Retained components and the last 8 variables in Table 1 were then regressed for each subsample.

3. RESULTS AND DISCUSSION

3.1 Results of PCA

All subsamples had significant Bartlett's tests and acceptable Kaiser-Meyer-Olkin (KMO), which was higher than the threshold of 0.5 (Field, 2013). These two indicators confirmed the suitability of the datasets to PCA. Four selected components were Hazard Knowledge, Hazard Perception, Trust, and Risk Information.

3.2 Results of ordered logit regression

A consistent result among three subsamples was the significant effect of trust and perception of hazards. The effect of other variables on risk perception tends to differ across countries. "Education" was only significant in Cambodia, while "Gender" determined risk perception in Viet Nam and Laos but not Cambodia. Homegrown vegetables and knowledge of hazards influenced vegetable risk perception in Cambodia only. Risk information and perception about the importance of vegetables in the diet shaped risk perception in Viet Nam but not in the other two countries.

3.3 Discussion

Trust is one of the two common determinants of risk perception across Laos, Cambodia, and Viet Nam. Consumers face difficulties in assessing food safety (Unnevehr et al., 2010). Holding personal trust in the government and others helps them reduce the complexity of food safety judgment, resulting in decreased risk perception of vegetables. Consistent with a survey in China (Chen, 2013), this paper confirms the role of trust in shaping food safety risk perception. Since trust in all institutions was low (Table 1), improving trust is one of the measures to address safety concerns in Laos, Cambodia, and Viet Nam.

Perception of hazards is another common predictor of vegetable risk evaluation in all studied countries. Consumers viewed all food hazards highly dangerous (mean scores from 3.56 to 3.9, Table 1). This view led to the perception that vegetable consumption is associated with high health risks. Noticeably, consumers perceived a larger threat from chemical hazards (pesticides, heavy metals), as compared to biological hazards (bacteria) (Table 1). However, according to WHO (2015), it is not chemical but biological hazards that are the main cause of food-borne illness in Southeast Asia. Consumers in our survey might be biased in hazard perception, which can cause a misinterpretation about vegetable risk.

Laos, Cambodia, and Viet Nam differed in some other factors influencing risk perception. Together with Taylor et al. (2012), we found that women perceived higher vegetable risk than men in Laos and Viet Nam. Women occupied about 70% and 80% of the sample in Laos and Viet Nam, respectively. Women are more responsive in ensuring household food safety. They act as a gatekeeper in selecting and preparing food for their families (Lin, 1995). Probably because of this role, risk perception was higher for women. This finding implies that women

Variables	**Laos** ***(n=328)***		**Cambodia** ***(n=300)***		**Vietnam** ***(n=571)***	
	Coef.	*SE*	*Coef.*	*SE*	*Coef.*	*SE*
Children	- 0.134	0.107	- 0.094	0.116	- 0.013	0.104
Age	- 0.011	0.011	- 0.004	0.011	- 0.006	0.009
Education	- 0.010	0.099	0.303**	0.135	0.066	0.104
Gender	- 0.570**	0.239	- 0.779	0.528	- 0.692***	0.217
LogIncome	- 0.471	0.393	0.856	0.572	0.507	0.217
Homegrown	0.038	0.263	- 1.336***	0.278	- 0.114	0.184
Vegetable Importance	0.159	0.147	0.336	0.269	0.238**	0.101
Vegetable Poisoning	0.025	0.147	- 0.053	0.056	0.237	0.111
Hazard Knowledge	0.060	0.115	0.732***	0.162	0.223	0.095
Hazard Perception	0.462***	0.114	0.291**	0.132	0.443***	0.090
Trust	- 0.238**	0.111	- 0.565***	0.142	- 0.160*	0.090
Risk Information	0.056	0.111	- 0.189	0.147	0.236**	0.096
McKelvey & Zavoina's R2:	10.40		39.40		16.80	

TABLE 3. Ordered logit regression results. Note: *, **, *** denotes significant level at 10%, 5% and 1%, respectively.

should be the target group of risk communication initiatives in Laos and Viet Nam.

Risk information determined risk perception in Viet Nam only. Risk perception is formed through a process of seeking, receiving, and processing information (Roberts et al., 2016). According to Ha et al. (2019), Vietnamese' exposure to intensive information about food safety incidents from mass media has given rise to food safety risk perception. Hence, adequate risk communication is needed to form Vietnamese consumers' unbiased food risk perception. Only in the Viet Nam subsample, perceived importance of vegetables shaped vegetable risk perception. Our survey revealed that vegetables were an essential cuisine for Vietnamese, as the mean score of "vegetable importance" is 4.2 out of 5 (Table 2). This suggests a high product involvement associated with vegetables in this country. Based on the perceived importance of vegetables and its positive relationship with risk perception, we recommend that better management of vegetable safety is urgently needed.

The presence of homegrown vegetables reduced the risk perceived of vegetables in Cambodia. There is a common belief that homegrown food is far safer than marketed alternatives (Green, Draper, & Dowler, 2003). Cambodian consumers who have homegrown vegetables, therefore, perceived a lower risk from their vegetable consumption. This paper highlights that supporting the self-provision of food in big cities in Cambodia would lower concern about food safety. In Cambodia, knowledge of hazards increased with vegetable risk perception. We previously expected that knowledge of hazards, a proxy of perceived control over food safety, would negatively affect risk perception of vegetables. However, our finding contradicts our previous expectation. More research is needed to retest the influence of food safety knowledge on risk perception in Southeast Asia.

4. CONCLUSIONS

Consumers in Laos, Cambodia, and Viet Nam perceive a considerably high level of vegetable safety risk. Reducing food risk perception is crucial due to its adverse impact on food consumption. This requires a better understanding of factors determining risk perception in these countries that have been ignored in previous studies. Using data from a survey of 1,199 consumers, we found that Laos, Cambodia, and Viet Nam have two similar determinants of vegetable risk perception: trust and knowledge of hazards. These countries were different regarding other predictors of risk perception. Risk perception was higher for females in Laos and Viet Nam. Results show that the importance of vegetables in the diet, and risk information shaped risk perception in Viet Nam but not in the other two countries, and hazard knowledge and the presence of homegrown vegetables affected risk perception only in Cambodia. From a policy perspective, addressing public concerns over vegetable safety in developing countries in Southeast Asia will require an improvement of consumers' knowledge of food hazards and institutional trust. However, since some factors shaping food risk perception vary among the three countries, risk communication should be country-specific. Heightened risk perception can generate a profound impact on food consumption. If vegetable safety is not managed properly, loss for the domestic vegetable sector is unavoidable in developing countries in Southeast Asia.

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Climate change adaptation in disaster-prone communities in Cambodia and Fiji

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ABSTRACT

This article examines how rural communities living in flood-prone river basins of Cambodia and Fiji have responded to increasing variability of floods and other natural hazards under the influence of climate change and other risk factors. Particular emphasis is placed on risk perceptions and adaptive strategies of households and communities with regard to regular and catastrophic floods and how the livelihoods of vulnerable groups are affected by floods and other climate-induced disasters. Our research approach integrates the food, water and energy security nexus with the rural livelihood framework. The study aims at identifying the spatial extent and dynamics of flood events and determining the factors that enhance adaptive capacities of flood-affected communities and households. Our study finds that access to resources as well as local socio-cultural contexts are important determinants of coping and adaptation practices at the community and household level in the two countries. Findings also suggest that research participants had a profound understanding of flood flows, extent and impacts that complements knowledge gained from hydrological and remote sensing methods. We conclude that blending local and scientific knowledge is a promising approach to enhancing adaptive capacity and resilience.

KEYWORDS

Asia-Pacific, Climate change adaptation, Disaster risk management, Local knowledge, Participatory research, Rural livelihoods

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HIGHLIGHTS

- Research participants had a good understanding of hazards and appropriate actions.
- Local and scientific knowledge can be combined to alleviate climate-associated risks.
- Socio-cultural factors play a crucial role in disaster risk reduction capabilities.

1. INTRODUCTION

Adaptation to climate change tends to refer to long-term, permanent or ongoing changes made by communities, households or individuals in an attempt to mitigate the impact of future climate-related hazards. Adaptive capacity has been described as the "ability to experiment, innovate and learn, to act on new information in response to change and disturbance", while coping strategies refer more to the "short term responses that allow for survival" (Fernández-Giménez, Batkhishig, Batbuyan, & Ulambayar, 2015). This study questions this distinction, looking instead at how coping strategies often transition into long-term adaptive change. Challenging the distinction between "adaptation" and "coping" is possible through recognition of how the post-disaster moment blends into a new pre-disaster phase, as well as how disaster response and relief efforts merge into more long-term attempts at risk reduction. By recognizing post-flood action as both reactive and preventative, this study attempts to be inclusive of the diverse ways in which people make decisions about which changes are acceptable, necessary and desired — cognizant of the fact that in many cases short-term coping strategies may be more appropriate than more permanent attempts at adaptation. Our study also challenges the idea that relocation can be imposed on "at-risk" communities without proper consultation and acknowledgement of new risk factors at the planned relocation site.

Cambodia and Fiji are among the 20 most-at-risk countries according to the WorldRiskReport 2019 (Day et al., 2019), primarily due to their high exposure to climate-related hazards. Cambodia constitutes part of the lower Mekong River Basin which is particularly prone to climatic changes. In analyzing future climate and hydrological scenarios for the Mekong River Basin, Hoang et al. (2016) predict significant temperature increases across the lower Mekong River Basin and increased precipitation in the upper catchment, with a high degree of uncertainty as regards the spatial distribution and direction of rainfall projections for the lower basin. As a small island nation, Fiji is particularly vulnerable to the effects of climate change (Lough, Gupta, Power, Grose, & McGree, 2015; Chand, Tory, Ye, & Walsh, 2017). Major consequences include sea-level rise and large-scale climatic events, such as tropical depressions and cyclones that can trigger flash floods, coastal and riverbank erosion, and landslides.

In both countries, strengthening community and household resilience and adaptability is of high priority. For the purpose of this study, we define resilience as the ability of households and communities to remain cohesive and functioning in the face of pressure and extreme perturbations. The objectives of the project are to: (1) identify the spatial extent and dynamics of flood hazards as a result of multiple risk factors; (2) determine the various factors that can enhance resilience and adaptive capacities of flood-affected communities in a changing environment, and (3) provide examples of successful community-based flood management and climate change adaptation that can inform strategies in similar areas of the two countries. The remainder of this article describes the multi-method research approach and analytical framework (Section 2) and then discusses the findings at the landscape, community and household level (Section 3). Section 4 summarises the main results of the study and offers some concluding remarks.

2. METHODOLOGY

2.1 Study sites

2.1.1 Prek Prasop District, Kratie Province, Cambodia

The northeastern province Kratie is one of the most disaster-prone provinces in Cambodia, with floods being the most frequent and severe climate-associated hazard. From 1996 to 2017, flood events in Kratie province adversely affected more than half a million people, damaged 1,715 houses and destroyed about 165,000 ha of crops. One of the most severely impacted districts is Prek Prasop, stretching along the western banks of the Mekong River. Additional environmental and social risks stem from hydropower development in the upper Mekong River Basin and deforestation. The district has a population of over 68,000 people divided into about 15,000 families (National Committee for Decentralization and Deconcentration [NCDD], 2015). The research was conducted in a total of 11 villages in four communes, with the most intensive fieldwork carried out in four communities, namely Thma Reab, Ou Long, Dei Doh Kraom and Kbal Kaoh.

PHOTO 1. Q-sort focus group in Thma Reab, Cambodia.

PHOTO 2. Participatory hazard mapping in Votua, Fiji.

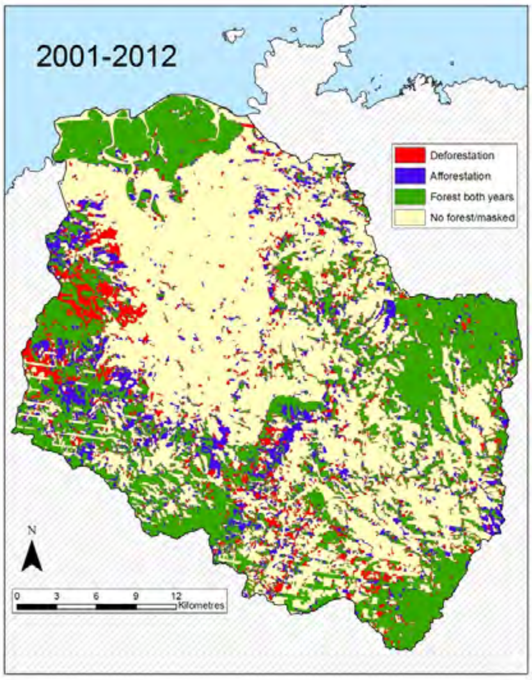

FIGURE 1. Change in forest/mangrove cover in the Ba River catchment from 2001-2012.

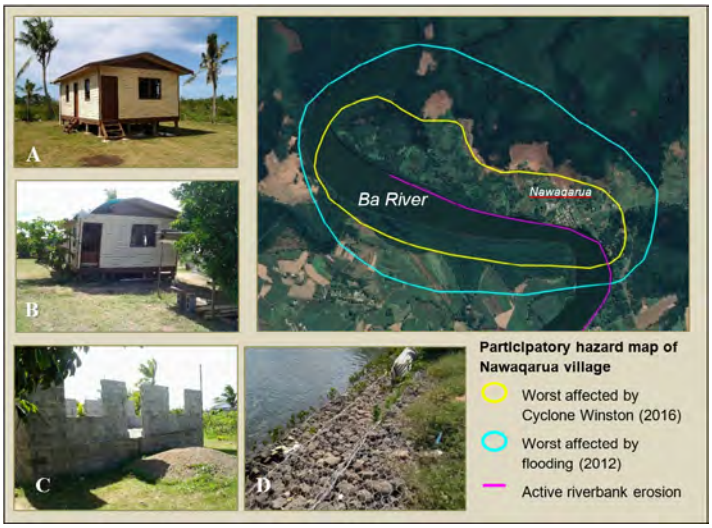

FIGURE 2. Illustration of exposure to multiple hazards at Nawaqarua village. The large map at upper right depicts hazard zones drawn by community members, indicating a spatial overlap of exposure to cyclones, flash flooding, and riverbank erosion. Inset photos (all taken within the village, indicated on map by "Nawaqarua"): A) New, government-funded house on stilts constructed to replace a dwelling lost in the 2012 floods; B) New house damaged by Cyclone Winston in 2016; C) New brick house under construction to replace house destroyed in Cyclone Winston; D) Engineering works to control riverbank erosion.

2.1.2 Ba River Catchment, Ba Province, Viti Levu Island, Fiji

Located in the most populated province of Fiji, the Ba River catchment in northwestern Viti Levu covers a total area of about 950 km^2 (Brown et al., 2014). Approximately 46,000 people live within the catchment boundaries, of whom about one third are iTaukei (indigenous Fijians), and the remaining two-thirds are Fijians of Indian descent (Brown, Daigneault, Tjernström, & Zou, 2018). Floods are the most frequent weather-related hazards that have affected communities in the downstream part of the Ba River catchment (Yila, Weber, & Neef, 2013). In a historical analysis, Yeo, Blong, and McAneney (2007) identified 28 major floods that affected the lower Ba River catchment between 1892 and 1999, with an increased frequency recorded since the most disastrous flood event of 1931. Further floods with disastrous consequences for local livelihoods occurred in 2009, 2012 and 2018 (Yila et al., 2013; Neef et al., 2018). Even hillside villages in the upstream part of the catchment, such as Navala, recorded some degree of flooding. Apart from Navala, most research focused on three communities—Votua, Nawaqarua and Etatoko.

2.2 Methods for data collection and analysis

The study is based on various fieldwork phases conducted in both study sites between November 2015 and November 2018. The research team employed an action-research approach combining scientific knowledge with the elicitation of local knowledge and local capacity-building. Qualitative data was collected using informal research conversations, semi-structured interviews, in-depth narrative interviews, and focus group discussions. Various interactive and participatory methods, such as ranking exercises, Q-sort methodology (only employed in the study area in Cambodia, cf. Photo 1), and participatory hazard mapping (Photo 2), were employed to examine how communities and households cope with and adapt to frequent flood events in a multi-risk environment. Computer-assisted qualitative data analysis software (ATLAS.ti and NVivo) was used to analyze the qualitative data.

For the scientific assessment of flood risks, we collected various types of quantitative data, such as topographic and hydrological data, information on land use and farming systems, socio-economic conditions and local water management systems. Remote sensing (RS) techniques were employed to derive information such as soil characteristics and land and vegetation cover in the target basins. Remotely sensed data at multiple spatio-temporal scales were used to map land cover change in the Ba River catchment. The RS-derived data was validated through field surveys. For the case of Prek Prasop District in Cambodia, Synthetic Aperture RADAR (SAR) images captured every 12 days at 10 m resolution from the Sentinel-1 satellite were analyzed. Otsu's (1979) method was used to automatically determine a backscatter threshold for separating low-backscatter water areas from high-backscatter non-water surfaces such as soil and vegetation. Permanent water areas were classified by thresholding the mean backscatter derived from all images captured between 2015 and 2018. Flood dynamics were mapped for 2018 (a severe flood event) and 2016 (a

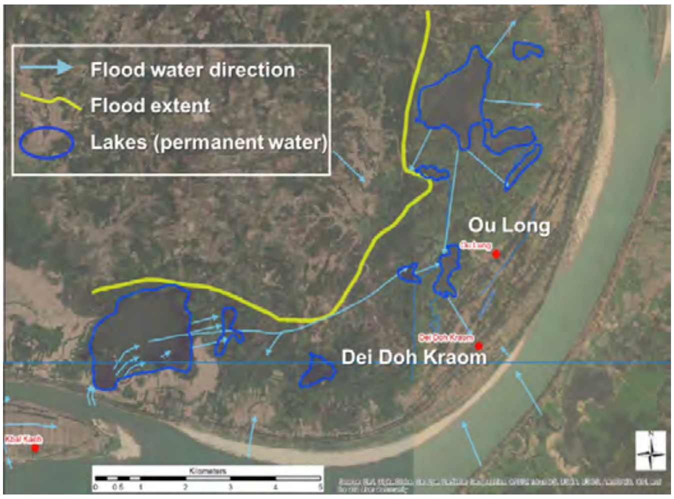

FIGURE 3. Flood water directions and flood extent in the lower part of Prek Prasop District (based on participatory hazard maps, M. Williams, June 2016).

drought year) by thresholding individual images.

Results from our study were reported back to the local communities as well as to government officials and NGO representatives in local dissemination workshops organized in 2019 to validate our research findings, share information and implement better flood protection and disaster risk reduction measures in the future.

2.3 Conceptual framework

In their working paper "Climate Adaptation, Local Institutions and Rural Livelihoods", Agrawal and Perrin (2008) argue that climate change is "likely to manifest around increased risks to rural livelihoods". These risks can be classified into four different types, including: risk across space, risk over time, risk across asset classes and risk across households (Agrawal & Perrin, 2008). Risks are mitigated, according to Agrawal and Perrin, through correlated strategies of adaptation including mobility, storage, diversification, communal pooling and market exchange (Agrawal & Perrin, 2008; Neef et al., 2018). Climate change adaptation is thus defined by the ability to achieve a "secure livelihood" in the post-disaster environment.

A "secure livelihood" is understood in our study as involving the intersection of food, water and energy security—as well as how security of these basic needs intersects with the security of sociocultural needs. A perspective of how the quality of these securities changes over time, in particular as a result of climatic variation, was crucial to the study. Communities and households were perceived as key actors in mitigating the effects of climate change and coping with flood impacts. Hence,

Statements	*Indicators*	*F1*	*F2*	*F3*
1	In the case of flooding, we move our farm animals and other valuables to higher ground	3*	2*	3*
2	We do not need to change our sowing and harvesting times to cope with flooding	-1*	0	1*
3	During floods, there are more fish to catch which compensates for the crop damage	-2*	-1*	-2*
4	We have changed our cropping systems to be better adapted to flood events	0	-1*	0
5	Many families have relatives in other locations that can support them during floods and droughts	-1	-1*	0
6	Many villagers had to move away permanently because of frequent disasters	1	0	-1*
7	During the flood, we grow crops in other locations where no flooding occurs	-2*	1*	-1*
8	Some villagers have insurance coverage against disaster events	-3*	-3*	-1
9	Before the flood arrives, we store enough food and water in our houses	2*	1*	2*
10	Sharing information with other households is very important during the flood	1	0	2*
11	The government does not need to take any action in our community to manage floods	-1*	-2*	-3*
12	Villagers do not support each other very much during floods and droughts	2*	-2*	-2*
13	Our own knowledge and experience is sufficient to cope with floods	0	0	1
14	We will need to grow different kinds of crops to cope with drought events	0	1	0
15	The government needs to help us when we suffer from a drought	1*	2*	1*
16	Following disasters, many villagers seek work outside the village to cope with the losses	0	3*	0
Percentage of explained variance of each Factor		35.37	31.65	16.29
Number of loading Q-sorts		5	6	2
Eigenvalues		4.60	4.11	2.12
Standard error of factor scores		0.22	0.20	0.33

TABLE 1. Factor arrays for the three factors representing hazard adaptation approaches. Significant factor loading at: +/-0.645 ($p<0.01$) – 99% confidence level.

their capabilities and constraints to alleviate climate-associated risks and adapt their livelihoods to a rapidly changing environment were the major focus of the study.

3. RESULTS AND DISCUSSION

3.1 Landscape-level analysis of land use change, flood causes and flood extent

Figure 1 shows significant areas of both deforestation and afforestation in the Ba River catchment over the period of 2001 to 2012. Overall, a greater area was afforested than deforested over the entire study period, resulting in a 15% increase in forest cover. Both deforestation and afforestation were concentrated in particular areas, the spatial arrangement of which influences the flood mitigation capacity of vegetated areas. Results highlighted the fine temporal scale of forest cover change in the upstream part of the Ba catchment. The ecosystem service role of forests in increasing flood resilience highlights the importance of incorporating forest cover change measurements in future assessment and monitoring of resilience in the Ba catchment.

Local knowledge was elicited during interviews and participatory hazard mapping sessions to gain insight into local perceptions of flood causes and understanding of flood flows and extent. Community members attributed the occurrence of severe floods to various factors, including upstream deforestation, high rainfall, sedimentation in the Ba River, and supernatural causes (flood disasters as an act of God). Research participants had mixed views on whether sediment dredging in the Ba River would mitigate flooding. Some villagers reported that mangroves areas were smothered by dredging mud, while others maintained that dredging created areas of higher or new land. Similarly, not all respondents thought that floods had only negative effects, as some noted an increase of nutrient-rich fine sediments and soil moisture. Participants in focus groups were able to show the distinct pathways of the flood and clearly delineate the extent of floods and cyclones as depicted in Figure 2 for the case of Nawaqarua village.

Similarly, in the study area in Cambodia, community members showed a profound knowledge of flood flows, extent and impacts, which was demonstrated during a series of participatory hazard mapping sessions (see Figure 3). At a local scale, this knowledge is more detailed

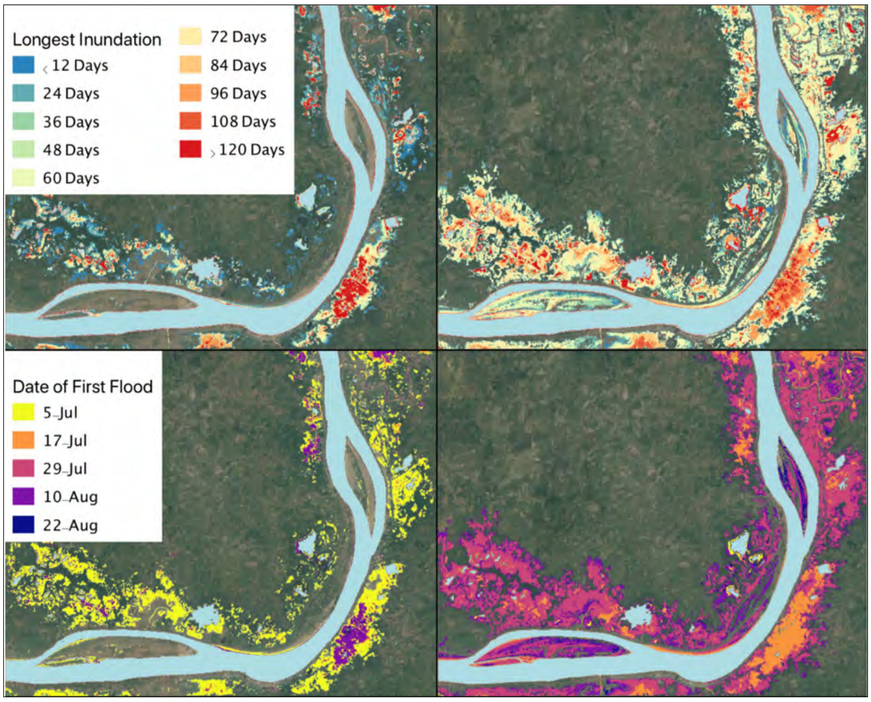

FIGURE 4. Flood dynamics as captured by Sentinel-1 SAR images. The maximum residence time of floodwaters based on images at 12-day intervals in 2016 (top left) and 2018 (top right). The first detected floodwaters in the 12-day interval images for 2016 (bottom left) and 2018 (bottom right).

than what can currently be gained from approaches in hydrology and remote sensing. Hence, drawing on both knowledge domains – local knowledge for detailed scale, scientific knowledge for broader scale and drivers – can provide communities, government decision-makers and scientists with a more holistic context to facilitate adaptation planning (for details on the methodological approaches to overcoming the challenges of combining scientific and local knowledge, see Pauli et al., submitted, and Mercer, Kelman, Taranis, & Suchet-Pearson, 2010).

The strength of the scientific method lies in the accuracy with which the residence period of floodwaters could be measured (see Figure 4). The various maps in Figure 5 demonstrate high inter-annual variability in flood residence time and onset of floods. The year 2016 was a drought year, and there was a severe sudden-onset flood event in 2018 due to an upstream dam collapse in neighbouring Laos. The pattern of flood flows corroborates community member's descriptions of the directions of flood flows, the location of "safe" areas and the maximum flooded extent.

3.2 Climate adaptation at community and household levels

Rural communities in Kratie Province's Prek Prasop District have lived with seasonal floods for a very long time. They have built houses on stilts to be able to keep their belongings dry and to store enough food, water and fuelwood to survive a flood that can last between one and

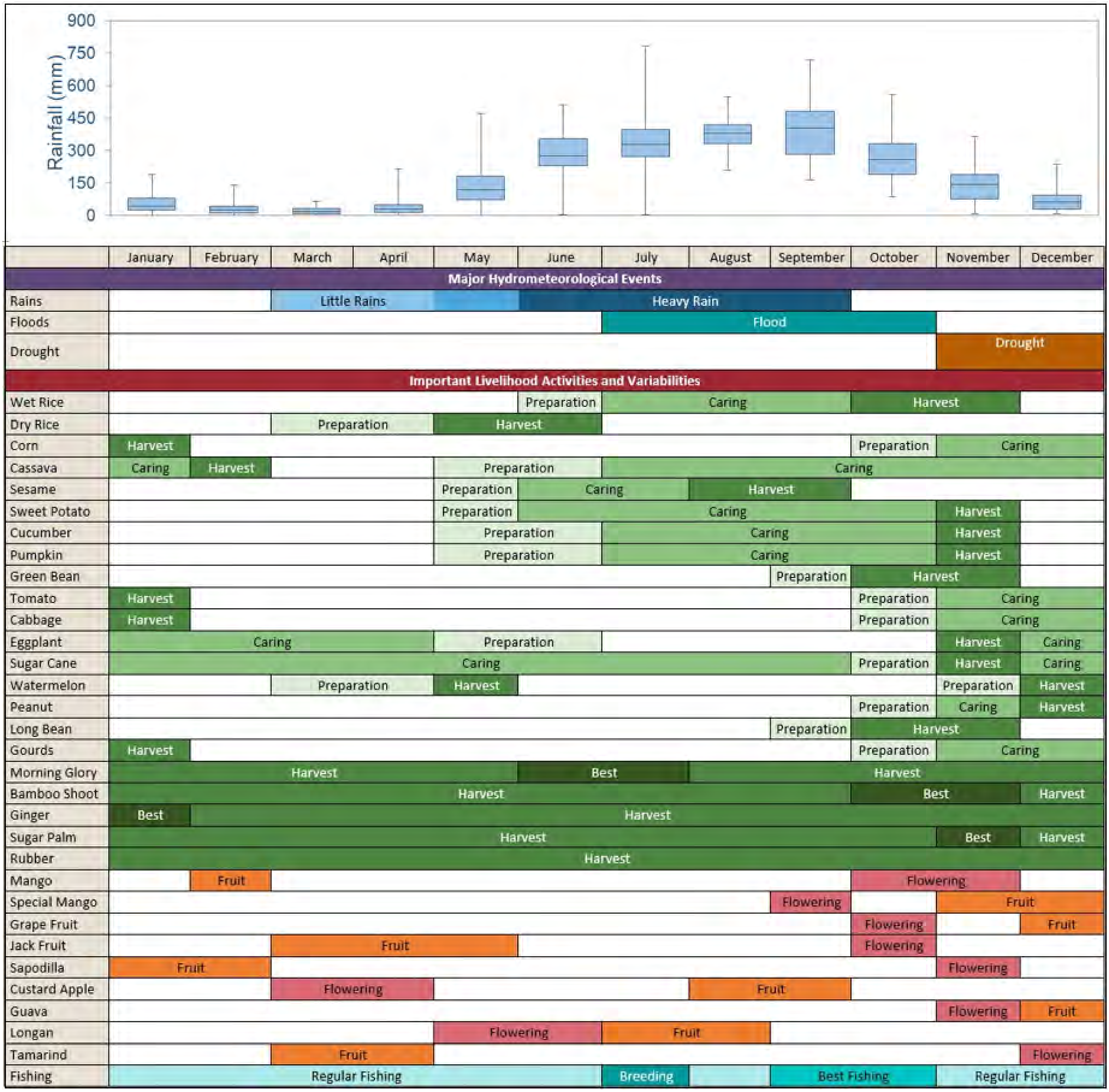

FIGURE 5. Seasonal calendar for the village of Dei Doh Kraom, Prek Prasop, Cambodia, collated from workshops conducted in November 2018.

two months. Wealthier households can further extend the height of their houses; thereby, they are in a much better position to cope with more extreme flood events than poorer households. More affluent households also have the financial capacity to buy farmland in safer places – such as upland areas – as a risk diversification strategy. Table 1 shows results from the Q-sort method, employed to understand differences in hazard adaptation approaches between household groups.

The columns in Table 1 are representative answers of three different groupings of participants (F1, F2, F3). The value in each column signifies the level of agreement for that statement of the groups (F1, F2, F3) that are associated with that Factor [-3 (strongly disagree) – 3 (strongly agree)]. If there is a *, then the value is significant, meaning that all the groups associated with that factor have expressed a similar sentiment.

All villagers participating in the Q-sort focus groups saw moving their assets to higher ground and storing foodstuffs as a reliable coping mechanism. Fishing does not offset crop loss during a flood event, and insurance is not a common practice or is not considered a feasible adaptation mechanism by local people. There was variability in the degree to which villagers helped one another, but most villagers felt that the government could provide more assistance, particularly during times of drought.

Villagers were indecisive as to whether they had sufficient knowledge to cope with flooding and whether crop diversification was appropriate for dealing with drought. Short-term coping strategies, such as finding temporary employment in neighbouring districts that are not affected by floods, were not distinguished from long-term adaptation strategies like adjusting cropping systems, as post-disaster recovery increasingly blends into the pre-disaster risk reduction phase, thereby blurring the boundaries between reactive and preemptive strategies.

Diversification was one of the types of adaptation practice which were less employed by female-headed households than male-headed households, according to findings from our household survey (Table 2). However, like for the other adaptation practices, the differences between male-headed and female-headed households were statistically not significant.

More detailed information on crop diversification in the communities in Prek Prasop District was gathered through seasonal calendars developed in focus groups. Figure 5 depicts a seasonal calendar based on the outcomes of a focus group in Dei Doh Kraom. This community reported the most diverse array of crops grown, thereby demonstrating a high potential of resilience to climate change and adverse weather events. The seasonal calendar includes the typical timing of important meteorological events (compared with rainfall data) and key livelihood activities. Crops depicted are a mix of those grown for home consumption and sold for income.

Research participants perceived that due to environmental change and upstream hydropower development, floods have become less predictable and more intense in Prek Prasop District. When the floods arrive in the villages, the male household members will bring all large livestock – cattle and buffaloes – to higher ground, where they stay with the animals until the floodwaters recede. Meanwhile, the women stay in the flooded village where they prepare energy for the family, collect fodder for livestock and take fish to the market. These floods cause mental stress and put lives at risk, but people have learned to cope through such temporary mobility patterns. Some communities have assigned certain places as communal refuge areas – such as a hilltop Buddhist temple ground in the case of Prek Prasop commune – where all male community members can stay together for an extended period. In other communities (e.g. Koh Tasuy), by contrast, flood refuge areas are privately built and owned, hence being able to escape with large livestock to higher ground in those locations depends on individual households' land assets and financial capital.

In both study sites, social networks helped to reduce vulnerability to hazards and insecurity. Strong bonds among community members and a culture of assisting one another during hard times were particularly pronounced in iTaukei (indigenous Fijian) communities in the Ba River catchment. In times of disaster, these social networks play a crucial role in resilience and recovery. Vulnerable community members – children, the elderly, people with disabilities and those who lost their homes – rely upon functioning social networks for support. Women in iTaukei communities were found to play a particularly important role in disaster response, often taking care of the most vulnerable, such as elderly relatives whose mobility was compromised.

Class of adaptation practice	*Male-headed households*	*Female-headed households*	*Chi-square (p-value)*
Storage	89.52%	82.93%	0.262
Mobility	64.52%	63.41%	0.898
Diversification	71.77%	60.98%	0.195
Communal pooling	66.13%	63.41%	0.751

TABLE 2. Gender-based differences in the use of adaptation practices in Prek Prasop District. Note: Out of the 165 households included in the survey, 124 and 41 households were headed by male and female household heads, respectively.

Evidence from our research in iTaukei communities also suggests that Faith-Based Organizations (FBOs) are an integral part of local communities due to their spiritual roles in the everyday lives of people (cf. Cox et al., 2019). Given the importance of religious beliefs, FBOs are considered more trustworthy as they have more local knowledge and religious links with local communities than secular or international Non-Governmental Organizations (NGOs). Disaster relief efforts at the community level are often organized around church groups, with women groups playing a particularly prominent role.

Among Fijians of Indian descent who mostly live in scattered settlements of extended families, formal community emergency response was found to be virtually non-existent. Research participants stated that they relied primarily on informal networks, e.g. neighbourhood connections with other farmers or prayer groups. The lack of land ownership poses particular challenges for adaptation among these communities. Agricultural leases are often based on crop yields from the land. Hence, when flood events reduce crop yields, it was more difficult for tenants to pay the annual lease fee.

While there are (controversial) plans for iTaukei communities to be relocated from areas with substantial risk, there have been no such provisions for Fijians of

Indian descent. Further, relocation without government assistance is complicated by the lack of available land and the high cost of surveying and titling land. There is also the risk that iTaukei relocations will displace Fijians of Indian descent, as experienced in the resettled Etatoko community where the lease of an Indo-Fijian tenant was cut short in order to accommodate the 17 relocated iTaukei households (Neef et al., 2018).

The examples of the first major climate-induced relocation processes in Fiji indicated in Neef et al., 2018, Box 1 provide a stark warning against external interventions that do not consider the social, cultural and historical context in a certain locality. Making decisions without proper consultation at the local level may make communities more vulnerable to the impacts of climate change or other – yet unknown – risk factors. The social fabric of a community can often change in response to relocation. This may trigger internal conflicts that disrupt the community's stability because the cultural and traditional values have not been adequately considered in the decision-making process. While the Fijian government's Planned Relocation Guidelines formally consider these aspects, they still need to stand the test in their implementation (Republic of Fiji, 2018).

4. CONCLUSION

Our study identified a high degree of congruence between the flood extent identified in participatory mapping sessions and the satellite-derived flood data which is consistent with previous research that found that there was a greater risk perception in areas of moderate or substantial flood hazards. This demonstrates that communities and scientists have a similar comprehension about the physical extent of hazards, although they might have different understanding about the causes of floods and the appropriateness of coping/adaptation strategies.

Our study found that sociocultural, political and economic factors provide the basis from which communities and households make decisions on climate change adaptation strategies. All communities have adopted a wide range of strategies in line with Agrawal & Perrin's (2008) framework according to their specific social, economic, and geographic situation. Access to resources, power, and information are key factors that inform communities and households in selecting appropriate adaptation strategies. External interventions that disregard the importance of local context are bound to fail. Our study also finds that the distinction between short-term coping strategies and long-term adaptation measures is problematic in contexts where communities and households are facing multiple risks and where post-disaster contexts tend to blend into new pre-disaster phases.

In conclusion, adaptation frameworks need to accommodate diverse values, traditions, and social structures, where one-size-fits-all adaptation approaches should be avoided. As communities and households increasingly have to adapt to multiple risks, they find it harder to anticipate whether certain adaptation strategies are appropriate for a range of hazards or only alleviate a particular type of risk. Combining local and scientific knowledge domains is a promising pathway to enhancing the adaptive capacity of communities and households in rural areas of Cambodia and Fiji.

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Models for payment mechanisms for forest ecosystem services in Papua New Guinea, Philippines and Thailand

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ABSTRACT

Forests of the Asia-Pacific region are being converted to other land uses or degraded because their ecosystem services have no market value. This project aimed to generate scientific knowledge on the design of effective payment systems for forest ecosystem services (PFES). The research was conducted at three sites where forests are facing increasing pressures: a community forest in Papua New Guinea, a sub-watershed forest in the Philippines, and a protected forest in Thailand. We identified ecosystem values, reviewed laws and institutions relevant to PFES implementation, assessed payment and pricing options, and proposed effective PFES models appropriate for each of the research sites. PFES schemes received positive responses from relevant sectors in all three sites. However, a lack of comprehensive understanding, especially on financing mechanisms and benefit distribution, may hinder PFES-project development. Capacity building of local governments and communities is needed to advance their action, that includes PFES mechanisms, effective forest management and sustainable agriculture.

KEYWORDS

Forests, Payment for ecosystem services, Willingness-to-pay

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HIGHLIGHTS

- Comprehensive analyses of key forest ecosystem services and their economic values; policies, strategies and institutions relating to effective forest management and sustainable livelihoods; and transaction costs and payments options are crucial for effective guidelines for PFES-project development. Successful payment mechanisms must address economic efficiency (cost internalization), social vitality (equitable benefit distribution and sustainable livelihoods) and ecosystem balance (resilience and sustainable ecosystem services).
- PFES may offer an alternative approach for effective forest protection, but successful development of PFES-projects requires comprehensive understanding from all relevant sectors, especially on financing mechanisms and benefit distribution. It is the first step in a long road ahead.

1. INTRODUCTION

Forests in the Asia-Pacific region are being cleared for other land uses or degraded because their ecosystem services have no market value. To reduce deforestation and forest degradation, people need to be more aware of forest ecosystem services and their values. Forest valuation can also provide decision-makers with information for land-use planning and forest management. The estimated values of forest ecosystem services can be used for the development of Payments for Forest Ecosystem Services (PFES) schemes (Costanza et al., 2014), which can provide an alternative source of funding for forest conservation and restoration.

A PFES scheme is a system for generating finance to protect and/or restore forests, based on the provision of one or more ecosystem services. The concept of PFES is based on the principle that those who provide forest ecosystem services (sellers) should be remunerated for the continuous provision of such services. At the same time, those benefiting (buyers), or others who are acting on behalf of the users (i.e. governments, non-governmental organizations (NGOs), etc.), should pay for the provision of the ecosystem services (Smith et al., 2013; Wunder, 2005).

There are high expectations that PFES could provide the necessary financial incentives for sustainable forest management; however, the PFES schemes have been slow to develop in the Asia-Pacific region. Factors hampering the development of PFES schemes include lack of stakeholder collaboration and lack of data on ecosystem service values to support PFES agreements.

The APN research project entitled "Effective models for payment mechanisms for forest ecosystem services in Papua New Guinea, Philippines and Thailand", aimed to generate knowledge on how PFES could contribute to forest conservation in areas where forests are facing increasing pressures. The research objectives were to (1) Identify a cost-effective and scientifically robust method to assess forest ecosystem services; (2) Determine key steps to establish the institutional frameworks and activities for ecosystem protection and service generation; (3) Compare pricing and payment mechanisms between voluntary and compulsory options based on scientific quantification and valuation of forest ecosystem services; and (4) Strengthen the capacity of stakeholders for identification, assessment and delivery of forest ecosystem services.

2. METHODOLOGY

The study's overall framework is shown in Figure 1.

2.1 Study sites

The project selected three different research sites to examine how PFES mechanisms could be developed in very different settings. The three case studies were: (1) Payment for carbon storage in a community-managed forest in Papua New Guinea (PNG); (2) Payment for maintaining and protecting forests in the upstream of a sub-watershed to reduce downstream flood damage in the Philippines; and (3) Payment for watershed forest protection in a protected national park to secure adequate water supply in drought-prone areas of northeastern Thailand.

The PNG research site was Ugalingu Forest, which lies within the Middle Ramu Block 1 Forest Management Area in Sogeram Valley, Usino Bundi District, Madang Province. The research site is located in the Central Hills, which consists of closely dissected steep-sided hills and short ridges that rise to 240 m above sea level. The research site holds over 1,400 ha of pristine lowland hill tropical rainforest. By protecting this forest from logging, the high carbon stocks that the forest holds would also be protected. The Philippines site (Silang-Santa Rosa Subwatershed and Cambantoc Subwatershed in the province of Laguna) is vulnerable to natural hazards, such as typhoons and floods, accelerated by climate change. The forests contribute to flood mitigation. The sub-watershed flows from the mountainous area of Silang, Cavite, passes through Silang-Sta. Rosa river, and eventually drains into the Laguna lake. Upland areas of the sub-watershed are composed of built-up areas, agricultural and mixed croplands, grasslands and mixed

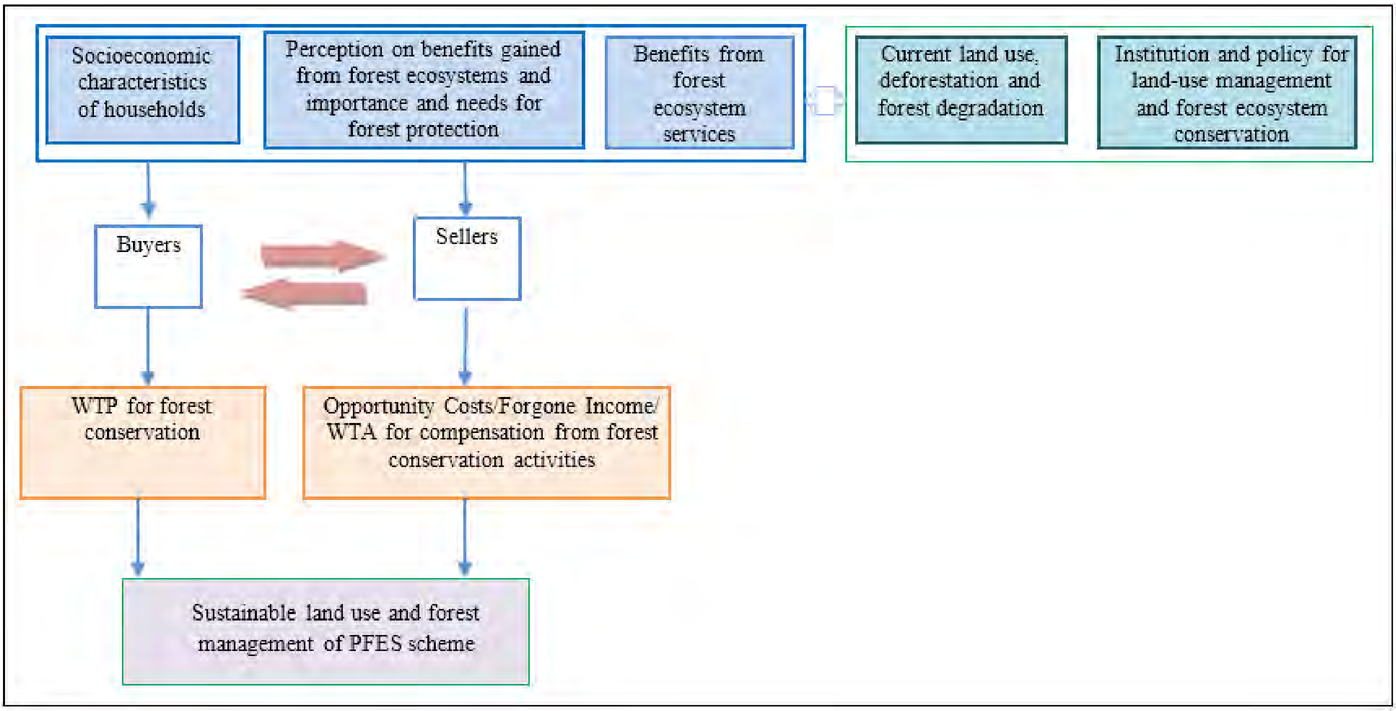

FIGURE 1. The overall framework of the study.

scrub, broadleaf or forest vegetation, while lowland areas are mostly used as built-up areas, grassland or idle land, and agricultural and rice fields. The Thailand site (Phu Kao in Phu Kao-Phu Phan Kham National Park in Nong Bua Lamphu province) provides water, drought mitigation and non-timber forest products (NTFPs) that support local livelihoods. The park is located between latitudes 16°46'–17°02' N and longitudes 102°24'-102°43'E, covering approximately 32,200 ha (322 km^2). Primary vegetation includes dry Dipterocarp forest (approx. 70% of the park), followed by mixed deciduous forest and dry evergreen forest (approx. 20% of the park area).

2.2 Methods

The methodology consisted of three sets of activities:

(1) Socioeconomic surveys and forest ecosystem services analysis, through forest measurements, field investigations, questionnaires and key informant interviews. At the PNG site, Verified Carbon Standard (VCS) methodologies were used to estimate the avoidance of emissions by protecting community-owned and managed forests from industrial-scale logging. In Thailand and the Philippines, buyers' willingness to pay (WTP) and sellers' willingness to accept (WTA) of PFES deals for forest protection were estimated, together with analyses of factors influencing villager decision-making using logistic regressions. The study used household questionnaires for cost-benefit analyses of ecosystem services by asking the respondent's WTP for ecosystem protection and sustainable service provision (following Khuc, Alhassan, Loomis, Tran, & Paschke, 2016; Boyle, 2003). A Contingent Valuation Method was used to estimate the monetary values of non-marketed ecosystem services (following Bateman et al, 2002; Carson, 2000).

(2) Analysis of policies, laws, strategies and institutions relating to forest protection and ecosystem service provisions. It was done through literature review and key informant interviews. Laws, policies and other institutions at national, regional and municipal levels were assessed on whether they help facilitate PFES-project development in each of the studied countries.

(3) Assessment of transaction costs and payment options (following Wunder, Engel, & Pagiola, 2008; Fripp, 2014). Several methods were used at each of the research sites to analyze transaction costs and payment options. These included the analysis of the profitability of farming systems based on questionnaire interviews of villagers and the analysis of opportunity costs for participating in PFES schemes (i.e. adopting tree-based plantations (Thailand), agroforestry farming systems (Philippines), and protection of forest carbon stocks [PNG]). The arrangements for setting up the PFES schemes at the research sites were drawn from discussion with villagers, government authorities and lessons learned from the research.

3. RESULTS AND DISCUSSION

At the Thailand study site, local livelihoods depend on agriculture, especially cash cropping of rice, cassava and sugarcane. The watershed forest provides water and NTFPs as food and income sources for the local communities. The average total amount of harvested NTFPs were 79 kg/household/year of which bamboo shoots, frogs and mushrooms were the three most common products. Two groups of direct beneficiaries of these forest ecosystem services were identified: (1) the three villages' members inside Phu Kao; and (2) villagers living outside the park. The estimated gross economic value of the NTFPs was 295 USD/year, or approximately 10% of the annual household income during 2018-2019. However, forest degradation from agricultural encroachment and harvesting of NTFPs at the Thailand site affected the watershed forest structure and ecosystem services, leading to inadequate water supply for agriculture and household uses. In the case of people living outside the park, continuing water shortage will affect farming and loss in their farm incomes with at least 32% of the annual household income. Nearly all of the villagers (98%) expressed the need for forest protection and restoration, emphasizing the importance of reforestation and effective water management in the watershed areas of the park.

The study received positive responses on the idea of PFES from local communities both those who live inside the park (sellers) and villagers living outside the park (buyers), with 56% of WTP and 55% of WTA, respectively. Key variables used in WTP and WTA models included (1) dummy variables for WTP of households living outside the park and WTA of households inside the park; (2) offered bid amounts for forest conservation; and (3) socioeconomic variables influencing household decisions (age, education, income, etc.). The estimated WTP was 4 USD/month/household, while WTA was 7 USD/month/household. The imbalance between demand and supply indicated an unattainable market unless financial subsidies are considered. Respondents who disagreed with the payment scheme expressed that PFES-project would reduce their benefits from the watershed forest, especially food sources and income generated from NTFPs.

The study also set up hypothetical conditions as part of a PFES project where agroforestry or a tree-based system was employed as a key mechanism to reduce forestland encroachment, especially due to agricultural expansion in the three villages inside Phu Kao. Switching from cash-crops to tree-based plantations introduces opportunity costs due to a decrease in cash-crop planting areas. Villagers provided data on monetary costs and benefits under major land-use types (rice, cassava, sugarcane, mixed perennials and forest), which were used to estimate opportunity costs of land-use change employing Net Present Value (NPV). NPV was calculated to estimate the profitability of land use over 10 years. An annual discount rate of 5% was applied for years with profit and 0% for years without profit. The calculated NPVs were: mixed tree and perennial crop cultivation, 4,342 USD/ha; forestlands, 178 USD/ha; rice, 6,934 USD/ha; cassava, 9,830 USD/ha.

Findings suggest that agroforestry and reforestation promotion as part of the PFES scheme will result in income loss for villagers who participate in forest conservation activities in Phu Kao. To reduce the impact as a result of income loss, while providing incentives to participate in PFES project development, villagers must be provided with sufficient compensation and/or alternative income sources such as from carbon offsets. Moreover, Thailand does not have specific legal support for PFES-project development, including implementation guidelines, rules and regulations and responsible authorities. This makes it difficult for PFES projects to develop and grow. The Office of Natural Resources and Environmental Policy and Planning should consider developing policies and plans, especially implementation guidelines with clear legal support, to facilitate PFES-project development in the country. Technical supports are also needed, and this can be provided by universities and research institutes working closely with local government and communities.

At the Philippines site, forest products were the most frequently chosen as key ecosystem services by respondents (36.82%), followed by water purification (20.90%), air purification (18.91%) and flooding mitigation (15.92%), respectively. Downstream households are the main beneficiaries of ecosystem services, particularly flood mitigation. The majority of households incurred income loss (about 63 USD per household) during severe flood events. Leading causes of deforestation and forest degradation in upstream areas were logging (84.58%) and forest conversion to agricultural lands (15.92%). The responses strongly expressed that human activities were the main responsibility for flooding. The majority of respondents in downstream areas agreed with the implementation of forests protection and rehabilitation activities, especially agroforestry in upstream areas. However, since farmers' adoption of sustainable forest/land measures in upstream areas will incur some income losses, downstream households should compensate upstream farmers through a PFES scheme. In upstream areas, most farmers' current land use is mixed perennials (40%), while 32% practice rice monoculture. The net return of rice monoculture (997 USD/ha) was lower than mixed agriculture (2,737 USD/ha).

The probability for downstream households to pay and upstream households to accept compensation for forest conservation is assumed to depend on their socioeconomic characteristics (age, years of education, income, etc.). The expected amounts of WTA per month (5 USD/household) from upstream households were higher than the expected amounts of WTP (7 USD/household) of downstream households. There is thus a need for negotiation on the ecosystem service's price. The study found that land conversion from forests to agricultural lands was a prominent reason for soil erosion in many cases. If tree-based systems are integrated into farming systems with other sustainable management measures to mitigate flooding and soil erosion at the research site, it will result in income loss for farmers. Conversion of rice monoculture to perennial monoculture (8,900 USD/ha) has the highest opportunity costs in the Cambantoc Subwatershed, while in the Silang-Santa Rosa Subwatershed, it is conversion of pineapple monoculture to mixed perennials (22,710 USD/year).

Adoption of nature-based approaches such as timber-based farming systems can contribute to flood mitigation. However, there is a need for a better understanding of tree species selection. Suitability of tree species to certain areas, profitability and ability to reduce surface run-off were found to be among the factors that can motivate farmers to adopt tree-based farming systems. Also, the research found that to avoid conflict, existing laws that govern natural resources must be compatible with PFES. Furthermore, coordination between organizations of the sellers and buyers is also crucial for effective and efficient management of PFES.

At the PNG site, the project researched the potential for PFES at Ugalingu forest. Ugalingu forest covers 1,400 ha and is owned under customary tenure by the Ugalingu clan, who reside in Koromosarik Village. The livelihoods of Ugalingu are largely subsistence-based, though small amounts of cash flow into the community through wage labour and sale of agricultural produce. The main agricultural cash crop is cocoa, with most households having a cocoa plot. Agriculture provides food on the table, and the forest provides supplementary food, materials for buildings and tools, medicines and cultural practices.

Ugalingu forest is a tract of pristine tropical rainforest that lies within an active logging concession. The study estimated net greenhouse gas emissions that could be avoided by protecting Ugalingu forest from the logging operation. Two land-use scenarios for Ugalingu forest over the next 30 or so years can be foreseen. The first is that the forest remains intact and undisturbed, as at present. The second and most likely scenario is commercial logging in the project area by an outside logging company using heavy machinery and in weak compliance with the logging code of practice, followed by the penetration of shifting agriculture in some parts of the project area. Verified Carbon Standard (VCS) approved methodologies VM0010 and VM0011 were used for the assessment. The research used existing inventory data and new primary data generated from a biomass survey using 12 of 35×35 m plots to estimate forest carbon stocks in aboveground living biomass for trees with a diameter at breast height (dbh) greater than 5 cm. The assessment estimated total avoided emissions over the first 10 years of a PFES project to protect carbon stocks in Ugalingu forest of 80,670 tCO2e.

In terms of national policies and institutions, there is no direct support for a community-based PFES scheme in PNG. Also, there is no single government agency responsible for overseeing a PFES exchange. Furthermore, if a PFES market were to be developed under current legislation, it would be completely unregulated (Crane, 2015). Protection of carbon stocks in Ugalingu forest from logging would be understood under the national policy as a REDD+ activity. PNG's National REDD+ Strategy allows project proposals from landholders, private sector actors and NGOs. However, they must be able to demonstrate clear competencies within the areas of project development and a strong commitment to the ongoing support and development of communities within the project location, as well as a secure long-term financial investment.

In estimating transaction costs for a PFES scheme to support the protection of forest carbon stocks by the customary landowners from logging of their forest, it was assumed that an NGO would manage the PFES project in PNG that has expertise in forestry and community development. The rough estimate of setting up PFES for Ugalingu forest protection was USD241,000.

4. CONCLUSION

Research at the three sites showed that development of PFES schemes requires a large amount of diverse information. This includes information on (1) ecosystem values, (2) policies and laws, (3) buyers' preferences and

	Thailand	*Philippines*	*Papua New Guinea*
Location	Phu Kao-Phu Phan Kham National Park in Nong Bua Lamphu Province -26% of the Phu Kao – Phu Phan Kham National Park area is part of the Ubolratana reservoir	Sta. Rosa-Silang and Bay-Cambantoc Subwatersheds, Laguna Lake region	Ugalingu forest (1,400 ha of pristine lowhill rainforest), Middle Ramu Block 1 Forest Management Area, Sogeram Valley, Usino Bundi District, Madang Province
Issue	Agricultural encroachment and harvesting of NTFPs has affected watershed forest structure, leading to inadequate water supply for agriculture and household uses.	Deforestation and land-use change, which is exacerbating downstream flood risk	Threat of industrial-scale logging to existing forest carbon stocks
Seller	Three villages located inside the park (1,600 ha)	Upstream households	Customary owners of Ugalingu forest
Buyer	Villagers living outside the park	Downstream households	Government or other party wishing to purchase carbon offsets
Services	Water provision, drought mitigation and NTFPs	Flood damage mitigation	Carbon storage in forest biomass
Analysis of payment scheme	– Monthly WTP per household (4 USD) and WTA (7 USD) – Conversion of cassava (9,830 USD/ha) and rice (6,934 USD/ha) monoculture to tree-based plantation incurred high opportunity cost. – Promoting tree-based plantation with sufficient compensation/carbon offsets is recommended.	– Monthly WTP per household (5USD) and WTA (7 USD) – Conversion of rice monoculture to perennial monoculture (8,900 USD/ha) has the highest opportunity cost in the Cambantoc Subwatershed – Local government units support reforestation activities and promote tree-based farming using their generated funds	-The estimated total avoided emissions over the first 10 years is 80,670 tCO2e. -Transaction costs for a PFES scheme to support the protection of forest carbon stocks by the customary landowners from the logging of their forest were approximately 241,000 USD/project
Local policies support for PFES	None available	None available	Can be supported under PNG's National REDD+ Strategy

TABLE 1. PFES scheme in different ecosystem services types differentiated in Thailand, Philippines and Papua New Guinea forests.

willingness-to-pay, (4) local community awareness, attitudes and perceptions on forest ecosystem services and their willingness to participate in a PFES scheme, (5) capacity of potential managers of the PFES scheme (communities, local governments, NGOs, etc.), and (6) activities that should be prioritized for forest management using the generated PFES funds. A first step before launching any PFES scheme is building the understanding of all stakeholders on the benefits of forest ecosystem services and the mechanics of PFES.

PFES can potentially provide an alternative source of financing for forest conservation and sustainable management of forests. All of the research sites were found to have the potential for PFES schemes, but there were also significant barriers. Analysis of WTP in Thailand and the Philippines showed that there is potential to generate funds locally from buyers of forest ecosystem services, but that the estimated WTA of sellers is higher than the estimated WTP of local buyers. In the case of PNG, the market price for carbon represents the WTP. Preliminary analysis suggests that this could be sufficient to cover a low-cost PFES scheme. For the research sites in Thailand and the Philippines, the results of WTP and WTA analysis can be presented to buyers, sellers and the local government as a starting point for negotiation on payment levels. The finding revealed that it is important for the local government and communities to have a good understanding of the mechanics of the PFES scheme and the benefits of adopting tree-based farming systems.

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Future changes in growing degree days of wheat crop in Pakistan as simulated in CORDEX South Asia experiments

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ABSTRACT

Climate change has become a global phenomenon having severe ramifications on socio-economic sectors such as agriculture, water resources, environment and health. The effects of changing climate are much more prominent on developing economies as compared to the implications on well-developed industrial powers. Pakistan is one of the struggling agricultural economies confronting the issues of food insecurity as a consequence of profound climatic conditions. Notable changes in climatic factors such as temperature can have a direct effect on Growing Degree Days (GDD) and may alter the growing season length (GSL). Growing season length is an important factor in ensuring that each crop developmental stage has a sufficient period for the transition to the next developmental stage. Lengthening or shortening of GSL can have dire threats to crop development and ultimately, production. This study has been conducted to assess the changes in GSL in response to the variability in daily maximum and minimum temperatures with a base temperature of 5°C across Northern, Central and Southern Pakistan. RCP 4.5 and 8.5 have shown an increase of 2°C and 5.4°C in minimum and maximum temperatures, respectively.

KEYWORDS

Agriculture, Climate change, Food security, Growing Degree Days (GDD), Temperature, Wheat

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HIGHLIGHTS

- Global warming in the coming years is expected to impact food security.
- Growing Degree Days (GDD) is an important parameter determining the crop development.
- Southeastern parts of Pakistan are likely to become unsuitable for wheat production due to temperature extremes over the mid-century.

1. INTRODUCTION

Temperature extremes are a global phenomenon having serious consequences, particularly in the agriculture sector, where it has considerably affected production in most of the developing countries (Elum, Modise, & Marr, 2017). This has created a highly vulnerable situation of food insecurity, especially in agrarian countries. In Pakistan, agriculture is one of the most important sectors that contributes about 18.5% to the GDP and provides occupation to more than 51% of the population. The principal crops include wheat, rice, sugarcane, cotton and maize. As in many other parts of the world, wheat is a popular cereal crop in Pakistan used as a staple food. Wheat, in Pakistan, holds high importance among all other cereal crops as it accounts for 8.9% value addition in agriculture and 1.6% in overall GDP with an area of 8.74 m ha under cultivation (Government of Pakistan, 2019). Despite being cultivated on such a large scale, wheat yields have undergone huge fluctuations since the year 2000 due to climatic uncertainties. Climate change, over time, has emerged as a key environmental concern. The cyclic pattern of weather has changed principally as a result of a rise in temperature which is one of the impacts of elevated concentrations of greenhouse gases in the atmosphere (Ahsan et al., 2010). The projections given by the Intergovernmental Panel on Climate Change (2014) have estimated that if the greenhouse gas emission rates continue to accelerate, an increase of 1.5 to 4.5°C is expected by the year 2100. In contrast, Hansen, Sato, and Ruedy, (2012) have reported, based on their estimations, a 0.18°C increase in average surface temperature every decade during the 21st century. Production in the agriculture sector is under serious threat due to the change in climatic trends all over the globe (Hu, Weiss, Feng, & Baenziger, 2005; Ding et al., 2006; Tao, Yokozawa, Xu, Hayashi, & Zhang, 2006; Iqbal et al., 2009; Semenov, 2008; Liu et al., 2010; van Ogtrop, Ahmad, & Moeller, 2014; Ahmad & Hussain, 2017; Ahmad et al., 2017: Dettori, Cesaraccio, & Duce, 2017; Abbas et al., 2017; Liu et al., 2018).

Increased temperature can have dire effects on crop productivity, and particularly, winter crops which show highly sensitive behaviours towards temperature change. Wheat appears to be one of the crops showing a higher degree of susceptibility towards temperature changes (Singha, Bhowmick, & Chaudhuri, 2006; Hundal, 2007; Pandey, Patel, & Patel, 2007). Climate change can cause up to 17% decrease in cereal yield, which is a severe reduction in the harvest as a consequence of elevated temperatures (Lobell, Bänziger, Magorokosho, & Vivek, 2011). Crop productivity either directly or indirectly bears the negative consequences of climate change, and the situation becomes inevitably serious in agrarian countries like Pakistan. It has been demonstrated in the study conducted by Aslam et al. (2017) that 1°C may cause a decrease of 4.1 to 6.4% in wheat yields. Zhao et al. (2017), Iqbal and Arif (2010) and Hussain and Mudasser (2007) reported similar findings. High temperatures, above the thresholds, is one of the main reasons for the reduction in wheat yield. The optimum temperature ranges for the wheat crop during anthesis and grain filling stage is from 12 to 22°C. If wheat is exposed to temperatures higher than 30°C at the time of anthesis or grain filling, it can have adverse effects resulting in a massive reduction in wheat yields (Nuttall, Barlow, Delahunty, Christy, & O'Leary, 2018; Farooq, Bramley, Palta, & Siddique, 2011; Porter & Gawith, 1999).

The growing degree days (GDD) is considered an important parameter determining the crop growth and development under different temperature regimes (Kalra et al., 2008; Kingra & Kaur, 2012; Meena & Rao, 2013). It assumes a direct and linear relationship between growth and temperature (Nuttonson, 1955). The crops sown on the recommended time have a higher heat requirement than those of later sown crops. This happens because of the lower temperatures during the early vegetative growth stages and comparatively higher temperatures at the time of reproductive stage (Khichar & Niwas, 2007).

This study is designed to assess the increasing daily maximum as well as minimum temperatures and to determine the impacts of rising daily mean temperature on heat requirements of wheat crop in wheat-growing zones all over Pakistan. The study applies RCP 4.5 and RCP 8.5 over two future time-slices, i.e. near-century and mid-century using the CORDEX datasets.

2. METHODOLOGY

2.1 Site selection

Pakistan is predominantly an arid country. The country area is divided into 10 Agro-Ecological Zones (AEZ) based on physiography, climate, land use and water availability. The main limitation for the development of agriculture in Pakistan is water shortage under high temperatures and aridity. Eighty out of the 131 districts (61%) in Pakistan encounters food insecurity and almost half (48.6%) of the population does not have access to sufficient food to have an active and healthy life.

Wheat is the first Rabi crop grown in the semi-arid, arid and rain-fed areas of Pakistan during the winter season. As the dietary staple of Pakistan, supplying 72% of caloric energy in the average diet, wheat ranks first among all the crops in the area under cultivation and production. This fact signifies its role in ascertaining food security at the national scale. In Pakistan, wheat sowing is usually carried out from mid-October to December and harvest from mid-March until mid-May. Figure 1 shows the selected case study sites in Pakistan.

The climate of central and southern Punjab is categorized as dry semi-arid agro-climate, a highly productive agricultural zone due to fertile soils and well-managed canal irrigation system. Wheat crop produced in the Punjab province contributes to almost 75% of the total production in Pakistan.

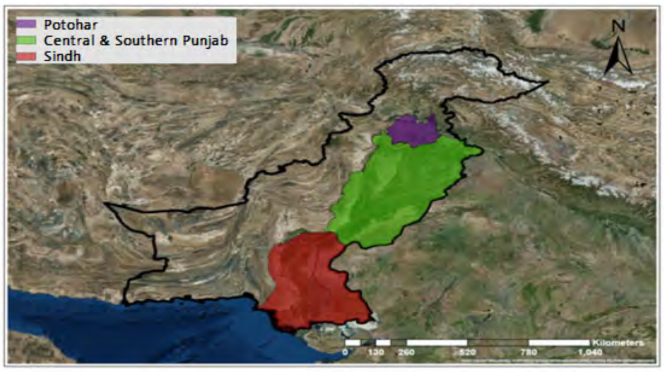

FIGURE 1. Case study sites of Pakistan.

The province of Sindh ranks second in wheat production. Wheat cultivated areas in lower Sindh are located in the irrigated plains which are fed by fertile alluvium soils deposited by the Indus River. Sindh has a hot and arid climate, with shorter growing season length and higher crop water demands as compared to the northern and central parts of the country. The growth duration of the wheat crop has a thermal dependency; short duration varieties are preferred for cultivation in the southeastern part, which matures in 100 to 120 days. Owing to climatic variations, crop periods range from November to March in lower parts and December to April in the upper plains.

The climate of Potohar region possesses semi-arid features in the southwest and sub-humid in the northeast. In a pluvial rain-fed region like Potohar, wheat cultivation depends on the available soil moisture at the time of sowing. Consequently, prolonged dry spell and late rain can drastically reduce crop yields. This region is considered to be the third-largest wheat contributor to national production.

2.2 Data

2.2.1 Baseline period and future scenarios

For the validation analysis, the baseline period was selected from 1981 to 2005 (25 years). Data of two climate change emission scenarios, Representative Concentration Pathways (RCPs) namely, Medium Controlled scenario RCP 4.5 and Business-as-usual scenario RCP 8.5 were evaluated for two future periods, near-century F1 (2006–2040) and mid-century F2 (2041–2070) periods.

2.2.2 *Observed and reanalysis data set*

Observed station data acquired from the Pakistan Meteorological Department (PMD) for the selected study sites were used to validate the selected reanalysis data.

Gridded data set (Harris, Jones, Osborn, & Lister, 2013) from the Climatic Research Unit (CRU), University of East Anglia, UK, was used as reference data to validate climate model data sets for observed climatology and model biases of monthly mean minimum and maximum temperatures over the historical period. Similarly, Reanalysis-gridded data, NASA-MERRA-II, was used for validation purpose for the period 1981 to 2005 for Tmin and Tmax over a daily time scale.

2.2.3 *Model data*

Six simulations using the Conformal Cubic Atmospheric Model (CCAM) (developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO)) were driven using the lateral boundary conditions of six Global Climate Models were validated against CRU over the historical period. These six simulations showed an almost comparable degree of biases over selected study sites over space and time. Subsequently, an ensemble approach was used, and all six CCAM simulations driven by six different GCMs were averaged using grid points of all dimensions for the selected variable. Ensemble approach was helpful to smooth the positive and negative biases and also to minimize errors.

2.3 Data analyses and techniques

Data analyses include plotting mean monthly biases of regional climate model data set with respect to reference data CRU for minimum and maximum temperature over Rabi season (Nov-May). Data is subset to a specified local region (Pakistan), and temporal and spatial interpolation was performed onto a common spatial grid using the bilinear interpolation scheme.

Growing Degree Day (GDD) bias was calculated for the historical period with reference to the MERRA data. Future projections of GDD were calculated. For calculating GDD, the first unit of the RCM data was converted from degree Fahrenheit to degree Centigrade. Later, the Rabi season was constructed which consisted of seven months, i.e. November to May. Seasonal aggregation was performed using Climate Data Operators (CDO) by first selecting November and December months from the year 1980/2004 and January, February, March, April, May from year 1981/2005. Both files were merged temporally, and resulting data were shifted ahead by two months in order to get 25-year data with all months of a season in every single year. In the next step, GDDs were accumulated in an individual season by first splitting all the years, each one containing daily values of GDD of the whole season (Nov-May), which were then added together to obtain the sum of a single season. Lastly, all seasons' calculations were merged to gather to get a single file of 25 years daily accumulated GDD during the Rabi season. Accumulated Growing Degree Days (GDD) were calculated using a base temperature of 5°C with the help of the following equation,

$$GDD_k = \sum_{n=1}^{D} max\left\{\left(\frac{TMAX_{nk} + TMIN_{nk}}{2} - B\right), 0\right\}$$

where GDD_k is the growing degree days accumulated through the growing season for the k-th weather station, $TMAX_{nk}$ and $TMIN_{nk}$ are defined as the maximum and minimum temperatures, respectively, for the n-th day of the m-th month for the k-th weather station, B is a baseline temperature below which it is assumed that no growth occurs, and D represents the number of days in the growing season.

3. RESULTS AND DISCUSSION

3.1 Observed climatology and model biases (Minimum and maximum temperature)

One of the most straightforward approaches to evaluate models is to compare simulated quantities, including global distributions of temperature, precipitation and solar radiation, with corresponding observationally-based estimates (Gleckler, Taylor, & Doutriaux, 2008; Pincus, Batstone, Hofmann, Taylor, & Glecker, 2008; Reichler & Kim, 2008).

This study compares the simulated temperatures of CSIRO-CCAM-RCM ensemble with observed MERRA 2 data, for Pakistan. Model simulations for maximum temperature (Figure 2) in Rabi (November to May) season show that the model was able to reproduce agreeable skill scores with a general trend of minor bias ranging from 0 to 1°C over selected study sites. In the northern region, the ensemble depicts a bias of relatively wider range (>4.5°C). However, wheat cropping zones, i.e. Punjab simulations, show a positive bias of 0-1°C and in Sindh, there is a negative bias of -0-1°C. Overall, patterns of temperature bias are nearly similar for observed data as well as model simulations. A study carried out by Ahmad and Mahmood (2017) determined the observed, simulated and projected extreme climate indices in Pakistan using CSIRO-CCAM ensemble for a historical period of 35 years (1980 to 2004).

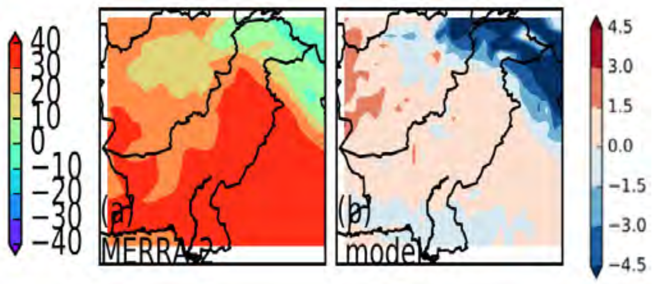

FIGURE 2. Bias estimation of Tmax using CCAM against MERRA-2.

Minimum temperature during early Rabi season is of utmost importance as the germination of the wheat seed depends on it (Ahmad & Shahzad, 2012). Seedling does not emerge if the required temperature conditions do not prevail. Figure 3 shows Tmin biases. CSIRO-CCAM has simulated minimum temperatures across the country with least bias of mixed nature in a greater portion of the country except for extreme northern parts where the largest values (>-4°C) of negative bias have been estimated. The findings of Ahmad and Mahmood (2017) also mark an increase of temperature by <1°C, which appears to be in strong agreement with our results. As Central Punjab estimations show a mixed trend

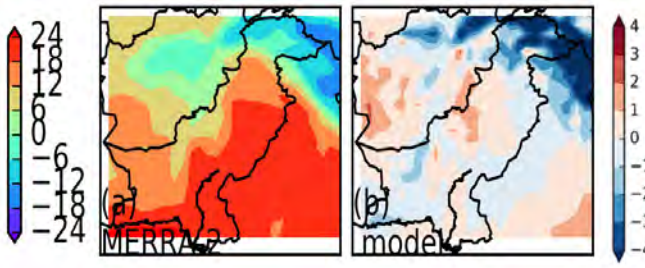

FIGURE 3. Bias estimation of Tmin using CCAM against MERRA-2.

with biases not higher than 1°C. Lower values of biases (Potohar <-1 °C, Sindh <+1°C and Central Punjab within 1°C) indicate that the results are reliable and model is recommended for simulations in the given area. A correlation of 0.99 and a standard deviation of 1.03°C were found between our selected model and observational data rendering the model as best pick for simulations of climatological parameters in Pakistan.

3.2 Observed climatology and model biases (Growing Degree Days)

Growing Degree Day (GDD) is a measurement of the heat accumulation above a specific base temperature. It relates plant growth, development and maturity (Parthasarathi, Velu, & Jeyakumar, 2013) in terms of specific GDD requirement of each phenological stage. On the whole, the growing season length and actual dry matter production critically depend on seasonal temperature conditions (Tsvetsinskaya et al., 2003). In the present study, the historical period consists of the growing season dating back from 1981 to 2005 for growing degree days of wheat crop during the winter season. For evaluation of CCAM model, MERRA-2 data has been used to collate bias estimation of CCAM for the historic period. The results generated by CCAM (Figure 4) are well-founded for GDD bias in wheat-growing zones of Pakistan. In areas of Potohar, Central Punjab and most of the Sindh territory, model estimation exactly overlaps the reference results showing no bias at all whereas in South-Western Sindh model estimates a bias of up to 100 GDD. Although the biases in the Hindu-Kush-Himalayan (HKH) region are conspicuous, yet they can be overlooked as the area of this study does not include the HKH region. The inferences drawn from the results for wheat-growing areas render the model as preferably recommended for bias estimation, specifically in the given area.

The reference figure showing results of MERRA-2 illustrates a wide range of heat requirement in wheat zones all over Pakistan. The magnitude of GDD goes on increasing linearly from Potohar to Sindh in a wide range of 3000 to 4500 heat units as determined by MERRA-2 data. The figure portrays that crop grown in Potohar requires the least heat units and stays in the

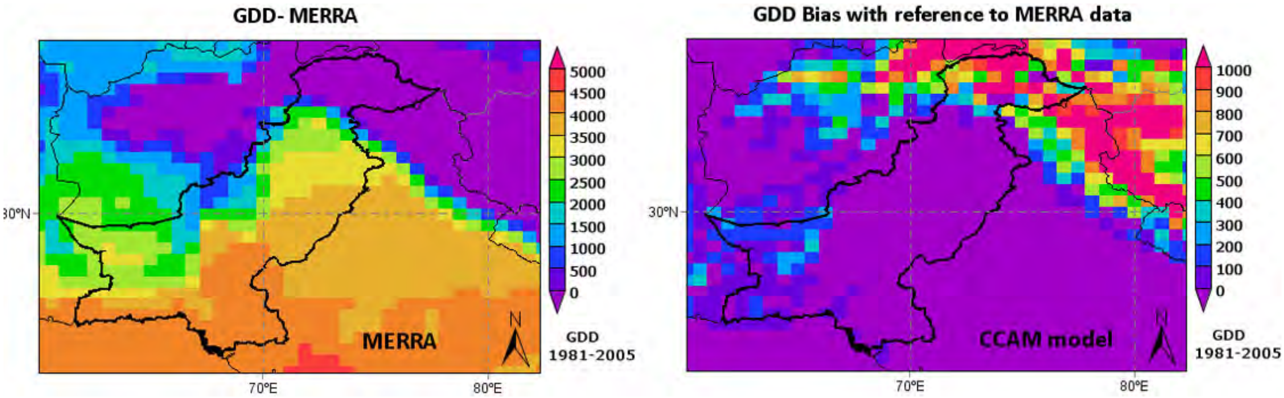

FIGURE 4. Differences (bias) between GDDs simulated by observed (MERRA) and model (CCAM) data during the historical period (1981-2005) in major wheat-growing zones of Pakistan. The figure on the left shows the average accumulated GDDs during the wheat-growing season as simulated by observed data; the figure on right shows the difference of average accumulated GDDs between observed and model data.

field for a longer duration (to accumulate the number of heat units required for maturity) than the crop grown in central Punjab and Sindh. The results of this study are in agreement with the findings of Ruiz Castillo and Gaitán Ospina (2016), where growing degree days for the historical period (1961 to 2004) ranged from 2400 to above 3,500 GDD.

3.3 Future changes in growing degree days of wheat crop in Pakistan

Figure 5 delineates the spatial distribution of seasonal GDD's required by the wheat crop all over Pakistan for three-time slots (near, mid and far century) under two RCPs (4.5 and 8.5). These maps aim to identify the areas with the greatest change in GDDs in the future over major wheat-producing areas in Pakistan.

The calculations for growing degree days are performed by obtaining the difference in daily mean temperature and base temperature. GDDs are accumulated by adding each day's GDDs.

The base temperature is the lower limit beyond which the plant cannot continue to grow and develop. In this experiment, the base temperature is assumed to be at 5°C (Gill, Babuta, Kaur, Kaur, & Sandhu, 2014). Base

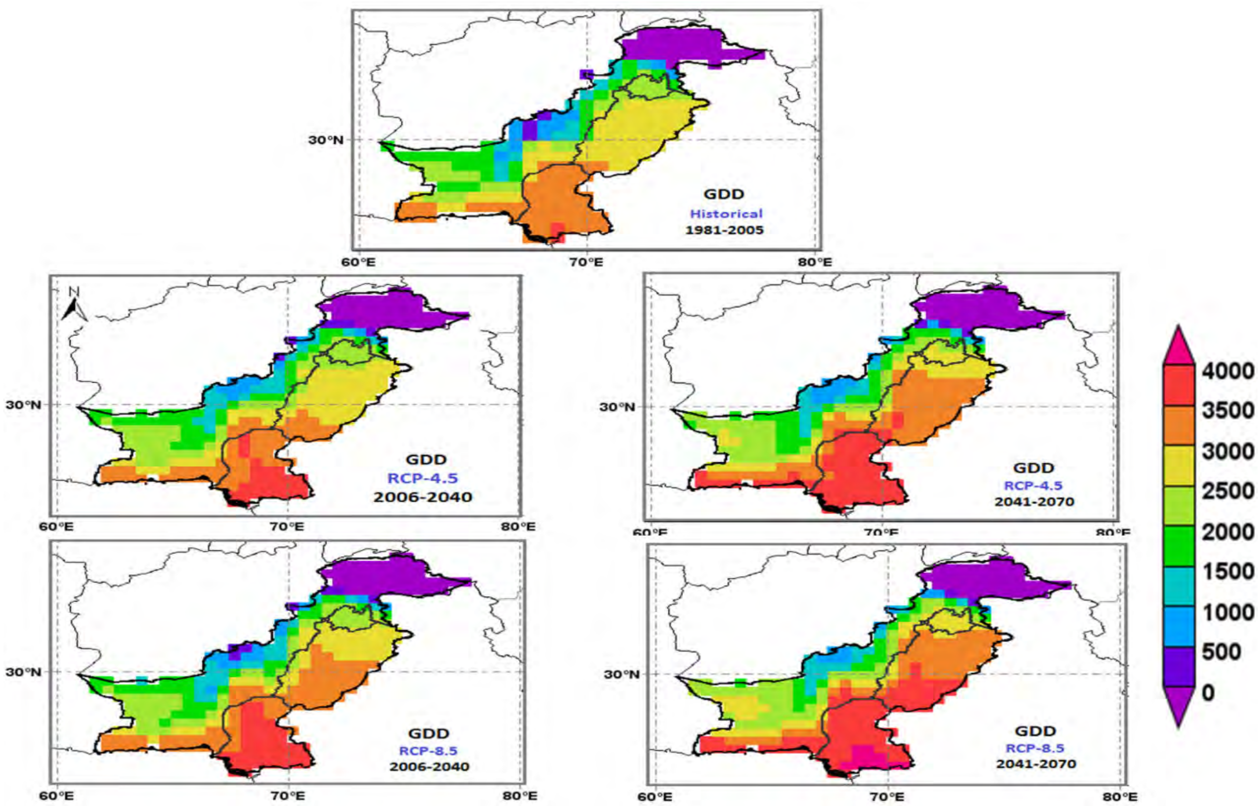

FIGURE 5. Spatial mapping of seasonal GDDs over Pakistan for control, F1 (near century) and F2 (mid-century) for RCP 4.5 and RCP 8.5 contribution during the season.

temperature can be different for each crop depending upon its genetic traits. An increase in the daily mean temperature indicates an accumulation of more degree days; shortening the crop duration accordingly which is very likely to be the reason for reduced crop yields (Ahmed & Fayyaz-ul-Hassan, 2015). Higher temperature together with reduced soil moisture decreases the season's length of crop growing which alters the plant growth stage and affects the partitioning and quality of biomass causing yield reduction (Hakim, Hossain, Silva, Zvolinsky, & Khan, 2012).

Figure 5 shows an increase in accumulated growing degree days in all major wheat producing zones of Pakistan including Sindh Central, Southern Punjab and Potohar region which is dominated by rain-fed wheat production under both RCP scenarios RCP 4.5 and RCP 8.5.

However, this increase is more intense in RCP 8.5 during mid-century. An overall increase of 1000 GDD between historical and late century extreme scenario in southeastern parts (lower Sindh province) of Pakistan has been observed. Results show the southeastern side of Pakistan, including wheat-producing districts of Sindh province (Thatta, Badin, Umerkot, Hyderabad and Sanghar) are likely to become unsuitable for wheat production due to temperature extremes during mid-century.

4. CONCLUSION

Daily mean temperature significantly affects phenology and grain yield of spring wheat. An increase in temperature is expected to shorten the crop lifecycle and lowering grain yields as a result of faster accumulation of GDDs in wheat crop. Studies indicate that temperatures in the southern part of Pakistan have shown to exceed the thresholds at the times of flowering and ripening. An overall increase of 1000 Growing Degree Days (GDDs) between past and mid-century extreme scenarios (RCP8.5) has been observed in case of wheat, implying that southeastern side of Pakistan is likely to become unsuitable for wheat production due to temperature extremes in future. An urgent response is required to help combat heat stress in cereal crops in order to ensure sustainability in food security. It requires high-quality research and policy planning for adopting to local scale, nationally oriented and forward-looking climate-smart practices and well-suited adaptation strategies, for resilient agriculture. Based on our study results, it is suggested that strategies like bringing more area under cultivation in North-Western and Mid-Western sides of Pakistan, considering multi-cropping and terracing options, early planting to avoid heat stress, and developing drought tolerant and heat resistant varieties can be wise options to minimize climate change impacts on wheat crop in Pakistan.

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Policy gaps and needs analysis for the implementation of NDCs on adaptation and loss and damage in Bangladesh, Nepal, and Sri Lanka

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ABSTRACT

The Paris Agreement requires Parties to prepare, communicate, and maintain successive Nationally Determined Contributions . Bangladesh , Nepal and Sri Lanka have submitted their NDCs which include mitigation as well as sector actions linked to adaptation and loss and damage. However, the countries face different faps and needs for the implementation of these commitments such as gaps and needs among others in laws and policies, institutional and technical capacity, means of implementation. This paper identifies gaps and needs in Bangladesh, Nepal and Sri Lanka for the implementation of adaptation and loss and damage components through legal and policy analysis, expert interviews, small group consultations, national and regional multi-stakeholder workshops. The research highlights the gaps and needs on laws and policies related to the implementation of NDCs, capacity (technical, financial, institutional and others), institutional and coordination setup, data access, research, and knowledge products as well as on measurement, reporting, and verification of adaptation and loss and damage actions, and gender-responsiveness on climate change policies. The research recommends to align, integrate, and build synergies between NDCs, National Adaptation Plans, Sustainable Development Goals, the Sendai Framework on Disaster Risk Reduction, and other related processes; to develop data and knowledge sharing mechanisms to address the identified technical and knowledge gaps; and to develop common national monitoring and evaluation systems for climate change adaptation and loss and damage related processes.

KEYWORDS

Capacity building, Climate change, National Adaptation Plans, Nationally Determined Contributions, Sustainable Development Goals, United Nations Framework Convention on Climate Change

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HIGHLIGHTS

- The NDCs are at the heart of the Paris Agreement and play a vital role in changing the world's course towards a sustainable pathway, and limiting global warming to 1.5°C to 2°C above pre-industrial levels.
- NDCs are not limited to mitigation, and many developing countries including Bangladesh, Nepal and Sri Lanka have submitted adaptation and loss and damage NDCs, or actions interlinked with these two components.
- For an effective implementation of NDCs on adaptation and loss and damage, there are many gaps and needs to be overcome.
- A gap analysis is necessary to identify the existing gaps and needs for the implementation of NDCs on adaptation and loss and damage, and to build synergies with other related processes on climate change adaptation, sustainable development and addressing climate risks.
- Building capacities and addressing existing knowledge gaps through regional and international cooperation will help bridge the gaps and address the needs related to the implementation of NDCs on adaptation and loss and damage.

1. INTRODUCTION

In 2015, 196 parties signed the Paris Agreement to change the world's course towards a sustainable pathway and limit global warming to 1.5°C to 2°C above pre-industrial levels.

One of the core elements of the Paris Agreement is the concept of Nationally Determined Contributions (NDCs). The Paris Agreement requires each party to prepare, communicate, and maintain successive NDCs. These communicated NDCs are recorded in a public registry and maintained by the United Nations Framework Convention for Climate Change (UNFCCC) Secretariat (UNFCCC, 2015). NDCs are submitted every five years, and the next round of NDCs, which could potentially include new or revised NDCs, is expected by 2020. To date, 184 Parties have submitted their first NDCs, and one Party submitted its second NDCs (NDC registry: https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx).

The NDCs submitted by countries are not only focused on mitigation but also interlink with sectors connected to adaptation and loss and damage. Furthermore, NDC implementation in a country is not a standalone activity but interconnected with different processes such as the National Adaptation Plans (NAP) process introduced under the Cancun Adaptation Framework (CAF) in Decision 1/CP16, FCCC/CP/2010/7/Add.1, the Sustainable Development Goals (SDGs) under the United Nations development processes, and the Sendai Framework on disaster risk reduction.

This research has as its objective to identify policy gaps and needs for the implementation of NDCs on adaptation and loss and damage in Bangladesh, Nepal, and Sri Lanka; to identify synergies and alignments between other related processes such as NAPs, SDGs, and the Sendai Framework; to share knowledge and expertise related to addressing gaps and needs; to develop regional cooperation in addressing and building synergies for the implementation of NDCs; and to develop multi-stakeholder driven, gender-responsive, inclusive and participatory recommendations to address the identified gaps and needs for the implementation of adaptation and loss and damage NDCs of the three countries.

NAPs build upon the experiences from the national adaptation programmes of actions and have their objectives as the reduction of vulnerability to the impacts of climate change by building adaptive capacities and resilience; facilitating the integration of climate change adaptation, in a coherent manner, into relevant new and existing policies, programmes, and activities, in particular development planning processes and strategies, within all relevant sectors and at different levels, as appropriate (UNFCCC, 2001a).

The guiding principles of NAPs indicate that NAPs should follow a country-driven, gender-sensitive, participatory, transparent approach and be undertaken in accordance with the convention. They should take into consideration vulnerable groups, communities, and ecosystems and be gender-sensitive. Guided by the best available science as well as traditional and indigenous knowledge, they should integrate adaptation into relevant social, economic, and environmental policies and actions without being prescriptive or duplicating the efforts of the country, instead facilitating country-owned and country-driven action (UNFCCC, 2001b).

To date, thirteen countries have completed their NAPs and shared them via the NAP Central platform maintained by the UNFCCC Secretariat. Additionally, some countries have developed a document or plan that is deemed to be equivalent to the country's NAP but has not been shared on NAP central. For example, Afghanistan has prepared a national adaptation plan which is not yet submitted to the NAP Central of the UNFCCC.

1.1 NDCs of Bangladesh, Nepal and Sri Lanka

Bangladesh, Nepal, and Sri Lanka have submitted their NDCs which included mitigation as well as sector actions linked to adaptation and loss and damage. All three countries have initiated the process for NDC revision for the submission of the revised NDCs by 2020.

1.1.1 NDCs of Bangladesh

Bangladesh communicated its first NDCs in 2015 for the period up to 2030, focusing on four key components which include mitigation, adaptation, NDC implementation, and support for NDC implementation.

The mitigation section of the NDCs includes the country's pledge to reduce its GHG emissions by 5% to 15% (subject to appropriate international support) by 2030 (Ministry of Environment and Forests, 2015) and the adaptation NDCs of Bangladesh presents the existing contributions from adaptation, plans to support adaptation, and synergies with mitigation measures. The NDCs also include key elements linked to NDC implementation such as governance and coordination at the national level and support needed for NDC implementation.

1.1.2 NDCs of Nepal

Nepal submitted its NDCs in 2016 (Ministry of Population and Environment, 2016), to reduce climate change impacts through adaptation actions to protect life and livelihoods of vulnerable climate communities. As a country with only a minimal contribution to global GHG emissions, Nepal focuses on adaptation and at the same time, aiming at increasing renewable energy production, and maintaining a low carbon pathway. Among key elements of focus on Nepal's adaptation NDCs are the formulation of the NAP to address the post-2020 adaptation needs; enhancing and implementing an Environment-Friendly Local Governance Framework; undertaking scientific approaches to address climate change adaptation needs. The NDCs focuses on loss and damage and aims to study and understand loss and damage associated with climate change impacts.

1.1.3 NDCs of Sri Lanka

Out of the three countries, Sri Lanka's NDCs was submitted in 2016 (Ministry of Mahaweli Development and Environment, 2016), and could be referred to as the most detailed. It consists of 14 sectors which include mitigation, adaptation, loss and damage, and means of implementation commitments. Among these the adaptation sectors focus on of health; food security (agriculture, livestock, and fisheries); water and irrigation; coastal and marine; biodiversity; urban, city planning, and human settlements; and tourism and recreation sectors. In addition to this, the NDC consists of loss and damage related commitments, and means of implementation for the NDC implementation.

1.2 Interlinkages and alignment with related processes

There are diverse processes such as the NAP, SDGs and Sendai Framework, which interlinks with NDCs on adaptation and loss and damage. This research focuses on identifying the existing synergies and potential alignments between the implementation of NDCs and other processes and building entry points to address the identified gaps and needs for the implementation of NDCs in the three countries of focus.

1.2.1 NDCs and NAP alignment

While Sri Lanka's NDCs on climate change adaptation closely link with the National Climate Change Adaptation Plan for Sri Lanka (2016 – 2025), i.e. the NAP of Sri Lanka, both Nepal and Bangladesh are still in the process of developing their NAPs.

1.2.2 SDGs and NDCs

All three countries NDCs refer to its objectives and commitments achieving sustainable development. This includes social and economic resilience building, setting up institutional mechanisms for the implementation of SDGs, and developing policies and road maps for achieving SDG indicators.

1.2.3 Sendai Framework and NDCs

Out of the three countries, the NDCs of Sri Lanka have a detailed component of loss and damage. However, when considering the country context, Bangladesh has interlinkages between their disaster risk reduction and climate change loss and damage related actions which include common actions on setting up a national mechanism on the Warsaw International Mechanism on Loss and Damage (WIM). However, none of the NDCs refers to Sendai Framework directly, while elements of the Sendai Framework are incorporated through different sectoral and related actions.

2. METHODOLOGY

This research paper has been prepared based on legal and policy analysis relevant to the NDC sectors on adaptation and loss and damage in the three countries, interlinked with a consultative process through interviews and sectoral- and national-level multi-stakeholder consultations. This includes a national workshop in each country, a regional workshop organised in Sri Lanka, fourteen consultations in Sri Lanka, two consultations in Bangladesh, two consultations in Nepal, five webinars with 184 registrations, and a series of recorded expert interviews. The workshops and consultations had a total of 350 participants and were held in cooperation with government entities under the NDC review process and focused on different NDC adaptation and loss and damage sectors and areas of gaps and needs. The process is further detailed in the four output documents together with the results, comprising country-level research papers on Sri Lanka, Bangladesh, and Nepal as well as a regional synthesis paper comparing the three countries (Wijenayake, 2019).

Key national documents on climate change, sustainable development, disaster risk management and disaster risk reduction, including the (I)NDCs, National Adaptation Programmes of Action, climate change policys, national communications to the UNFCCC, and Sri Lanka's National Adaptation Plan, and relevant sectoral policies were reviewed during the research. The findings of this research were validated through the above-mentioned consultation meetings and workshops. Additionally, the final research product has been prepared, taking into consideration the feedback and comments received from the meetings and workshops. Following the finalization of the national research paper, the findings were incorporated to a regional comparative study based on the country studies, and with additional expert comments through regional expert interviews, and inputs received through the regional workshop.

2.1 Methodology: National papers for Bangladesh, Nepal and Sri Lanka

The research methodology applied consists of the following components.

2.1.1 Policy gaps and needs analysis

Laws and policies related to all sectors that are included in the NDCs and the NAP, as well as related to cross-cutting thematic areas have been analysed to identify the gaps and needs on the laws and the policies for the implementation of relevant NDCs of each country.

2.1.2 Sectoral and national level multi-stakeholder consultations and workshops

Based on the initial legal and policy analysis for the laws and policies related to climate change and sustainable development, sectoral meetings were conducted for the adaptation and loss and damage NDCs related sectors. Key stakeholders from government entities, civil society organisations (CSOs), research institutions and think tanks, private sector, and academia were invited for the consultations. Data collection through consultations were based on discussions with the stakeholders and inputs on the present status of NDC implementation, and data provided on gaps and needs existing for the implementation of the sectors' NDCs by the participating stakeholders.

2.1.3 Preparation of the initial draft

Following the sectoral consultations, the first draft of the research paper was written. The findings of the research paper were presented at a national multi-stakeholder workshop, and the inputs received were incorporated to finalize the country papers.

2.1.4 Sharing of research findings via knowledge-sharing platforms

Following the activities listed in 2.1.1 to 2.1.3, the country research findings were presented to larger audiences via network meetings, related consultations and workshops, as well webinars for knowledge sharing on which country presentations were made focusing on different thematic focuses.

2.2 Regional comparative paper

The regional comparative research paper and findings were based on three steps which are listed below.

2.2.1 Synthesis of country research findings

Country research findings were synthesized to identify common gaps and needs among the three countries of focus. The findings of the regional paper were then shared on different platforms, online as well as regional consultations and workshops to gain insights for improvement. Based on expert interviews, existing research, the initial draft of the regional analysis was prepared.

2.2.2 Regional workshop for validation of findings

Following the drafting of the paper, the findings were presented to a regional audience during a two-day workshop where inputs were gathered for the reviewing and refining the findings. The final regional paper was completed based on the inputs and comments received, and additional input sought through online interviews from identified experts on adaptation, loss and damage and the UNFCCC process.

2.2.3 Sharing of findings

The final findings of the regional paper have been shared on different knowledge-sharing platforms including the Adaptation and Resilience Knowledge Hub developed as part of the regional research project, as well as webinars organized for sharing findings with regional and international stakeholders.

2.3 Summary of the participants and the activities

The following table presents a synthesized summary of the participation of different stakeholders, and activities conducted for the preparation of the national and regional gaps and need analysis of the NDCs on adaptation and loss and damage in the three countries of focus.

	Consultations	*Workshops*	*Participants*
Sri Lanka	14	1	200
Nepal	2	1	44
Bangladesh	2	1	50
Regional	–	1	56
Total	**18**	**4**	**350**

TABLE 1. List of activities conducted and the participation of different stakeholders.

3. RESULTS AND DISCUSSION

The research activities implemented in the three countries and the regional comparative paper have identified the following gaps and needs for the implementation of NDCs on adaptation and loss and damage, comparing the implementation plans and policy landscape across the different national sectors.

3.1 Bangladesh

For Bangladesh, the research identified a number of gaps and needs regarding the implementation of the adaptation and loss and damage component of the NDCs. The Government of Bangladesh has committed to formulate a NAP and implement the NDC adaptation components through it. There is a number of policies and strategies to support this process, but a lack of clear institutional mandates.

Sector	*NDCs of Bangladesh*	*NDCs of Nepal*	*NDCs of Sri Lanka*
		Mitigation Sectors	
Energy	Rural Electrification	Renewable Energy (NDCs 5, 6, 7, 8, 14)	Energy (Electricity Generation)
Transport and Infrastructure	Resilient Infrastructure	Transportation (NDCs 10, 11)	Transportation
Industry	Industry		Industry
Waste Management		Solid Waste Management (NDC 5)	Waste
		Adaptation / Adaptation-Related Sectors	
Health	Health		Human Health
Food Security	Food Security	Agriculture (NDC 5)	Food Security (Agriculture, Livestock, Fisheries)
Water	Water Security		Water and Irrigation
Coastal and Marine	Flood Control and Coastal Erosion, Coastal Zone Management,		Coastal and Marine
Ecosystems	Ecosystems, Community-Based Conservation	Forestry (NDCs 5, 12, 13)	Biodiversity, Forestry
Human Settlements	Urban Resilience		Urban Infrastructure and Human Settlements
Tourism and Recreation			Tourism and Recreation
Loss and Damage	Disaster Management, Social Protection and Livelihoods	Climate-Induced Disasters (NDC 4)	Loss and Damage

TABLE 2. Comparison of NDC implementation plans of Bangladesh, Nepal and Sri Lanka and the policy landscape across different national sectors.

Bangladesh has not finished its NAP and is, therefore, missing a key component of its framework for adaptation-focused climate action. Gaps and needs related to institutional capacity, knowledge and awareness about adaptation and loss and damage related actions, and lack of coordination between different government institutions constitutes were also highlighted. The proposed institutional setup for NDC implementation is not yet functional. Research also highlighted the need for boundaries and responsibilities to enhance the transparency, and the cooperation and coordination between the relevant ministries, agencies, and departments.

Bangladesh has developed its NDC Implementation Road Map. However, one of the critical needs remains the inclusion of detailed financial and technical support, and the integration of NDC adaptation sectors into the main sectoral plan, programs, projects, and policies.

Additionally, climate finance for adaptation and loss and damage actions has already been identified as a need, as the current adaptation funding is allocated predominantly from the national budget (approximately 1% of the GDP). Besides, an assessment of resource and capacity needs is also identified as a key need for the mobilization of adequate resources and private sector engagement for adaptation action.

Further, the need for enhanced focus on loss and damage was identified. The thematic focus is addressed through different ways (safety net programme, disaster management and relief, emergency support, agricultural loans and subsidies), but continues to be left out from being integrated into the institutional structure and policies. This remains a gap and should be addressed, as Bangladesh is a highly vulnerable country to climate risks and climate-induced disasters.

MRV processes for adaptation and loss and damage NDCs is also a gap that has been identified for Bangladesh. The country at present does not have a detailed plan for the monitoring, progress tracking, and reporting of the national NDC/NAP implementation. Gaps and needs in monitoring and evaluation must be addressed to ensure effective, accountable and transparent NDC actions in Bangladesh.

3.2 Nepal

Among the gaps and needs for the implementation of adaptation and loss and damage components in Nepal are improved institutional coordination as well as integrated actions. Further, capacity gaps and needs for the implementation of NDCs among key stakeholders have also been highlighted through research findings.

Like Bangladesh, Nepal is currently in the process of formulating their NAP, which is aimed to serve as a vehicle for the implementation of adaptation actions.

The research also highlights that some of the key sectors for adaptation action, such as water resources, public health, and urban settlements and infrastructure which are not included in the NDCs of Nepal. This highlights the need for reviewing the NDCs to include the country priorities, the key vulnerable sectors, and synergies between SDGs, and other developmental processes.

Additional gaps and needs highlighted include the lack of explicit targets for loss and damage, which is included through the references to the climate-induced disasters sector. MRV system remains a gap requiring a mechanism to be set up, and the capacity for reporting and tracking progress of the NDC implementation has also been marked as a gap to be addressed. There is also the need to introduce a comprehensive MRV system for the relevant government agencies, development partners, and the private sector. This is expected to address the gaps existing in climate finance tracking, which relates to local level funding, budget tagging, and increasing the accessibility of finance to local entities.

Furthermore, defining the role of development partners, the private sector, and local authorities has been identified as a need for improved multi-stakeholder driven NDC implementation in Nepal.

3.3 Sri Lanka

Among key policy gaps and needs identified for the implementation of NDCs on adaptation and loss and damage are the non-existence, or the non-implementation of laws and policies for the implementation of the relevant NDCs in the country. This is due to the outdated sectoral policies or needing amendments to address the changing climate vulnerabilities and developmental priorities. For example in the health sector in Sri Lanka, the need for re-evaluating the existing policies concerning migrant workers has been identified through the key stakeholder consultations, due to risk of malaria being re-introduced to Sri Lanka through undocumented migrant workers arriving in the country.

Further gaps and needs are related to the capacity to engage with UNFCCC processes and NDC implementation. The interviewed stakeholders who are engaged in the research activities reported the need for capacity building on technical expertise linked to thematic areas on adaptation and loss and damage NDCs. Furthermore, there is also a need to have the calculation of losses and damages to provide an accurate amount of the climate-induced losses and damages, as well as the implementation of NDCs related to loss and damage.

Additionally, there is also a necessity for institutional capacity building for enhanced and improved coordination to implement NDCs, and the gaps in mandates for coordination, data sharing and access to information. There are gaps in the implementation of NDCs activities due to a lack of ownership of activities related to NDCs by the sectoral ministries. Mandates for NDC sectoral coordination remains a gap and is aimed to be addressed through the enactment of the Climate Change Commission Act, which is at present in a draft form. It should also be noted that there are gaps in building synergies and the integration of climate change adaptation, and losses and damages due to climate-induced hazards and risks into the developmental processes such as SDGs, and Sendai Framework.

Among other gaps and needs noted through the research activities include the need for enhanced stakeholder engagement in climate change adaptation and loss and damage activity implementation under the NDC process. The increase of voices of the vulnerable communities in the decision-making processes was also identified as a key means for building resilience among vulnerable communities and ecosystems to climate change impacts.

Access to climate data needs for research in different climate-related sectors is also among the key gaps and needs identified. Moreover, the need for mobilising climate finance for adaptation and loss and damage actions, the capacity of different stakeholders for the development of bankable proposals was also noted as a gap to be addressed.

Gender-responsive climate policies and plans have also been marked as a need to be addressed, including awareness creation on the implication of gender on the climate actions, and the need for incorporating gender-disaggregated data for developing climate risk and vulnerability assessments.

MRV processes for climate actions in Sri Lanka remain in early stages. There is a need, as in Bangladesh and Nepal for the introduction of budget tagging system of climate finance for adaptation and loss and damage, monitoring and evaluation of climate action, and publicly accessible data on the implementation and progress of the implementation of NDCs of Sri Lanka.

The table on the following page lists the identified gaps and needs in all three countries and matches them up wherever possible.

3.4 Regional gaps and needs

Bangladesh, Nepal and Sri Lanka share some aspects of commonality. Among the gaps and needs that have been identified as common to all are, the need for enhanced institutional and coordination mechanisms for NDC implementation, and the need for developing synergies between existing developmental processes.

Sri Lanka	*Bangladesh*	*Nepal*
	Policies and Laws	
Lack of laws for implementation of NDCs or lack of application of existing laws	Need to strengthen governance for effective implementation of NDC adaptation components	
Need to expand sectoral policies to address adaptation commitments	Need to develop a more detailed policy landscape for financing mitigation and adaptation actions	
Opportunity to integrate climate change adaptation into sectoral laws and policies	Need of detailed road maps for transport, power, and energy sectors	Need to include water resources, public health, urban settlements, and infrastructure into NDC sectors
Opportunity to strengthen the integration of SDGs and NDCs to create synergies between both processes	Need to integrate NDC adaptation sectors into the ADP, sectoral plans, programs, and projects, five-year plan etc.	Need to enhance alignment of sectoral target with national priorities and to enhance alignment of NDCs and SDGs
Need to improve integration with and awareness of WIM and the Sendai Framework	Need to integrate loss and damage into different institutions	Lack of explicit targets related to climate-induced disasters and loss and damage
Need to integrate climate-induced migration aspects into loss and damage sector		
	Institutions and Coordination	
Need for enhanced coordination with sectoral ministries and entities	Need to establish effective coordination among ministries and other government institutions	
Need to enhance mainstreaming of climate action		Need to mainstream adaptation and climate risk assessments into local-level processes
Lack of coordination between different government entities and local stakeholders	Lack of coordination among different government institutions	Need to include local government and give ownership to them
Challenge of overlapping institutions and mandates		
		Opportunity to improve stakeholder engagement and increase participation and inclusivity in NDC review and implementation
	Capacity and Awareness	
Need to build capacities, awareness, and technical expertise on climate change, climate risk, and climate action among government entities	Need to build capacity within government ministries and line agencies to effectively coordinate, streamline and implement NDC related actions	Opportunity to build local government capacity and awareness and strengthen local climate action
Need to enhance capacities of legal policy experts drafting laws and policies related to climate change		
Lack of awareness on climate change, climate isk, and climate change adaptation	Lack of awareness about the adaptation part of the NDC to concerned agencies and different agencies	
	Data and Research	
Need to enhance monitoring and surveillance systems in several sectors		
Need for research in many areas to effectively address climate change		
Absence of data and data-sharing mechanisms in many sectors		
Need to strengthen early warning systems and meteorological data collection		
	Other	
Financial and technological gaps	Lack of a practical roadmap on for adaptation finance; need to include detailed financial and technical support into the NDC road map	
Need to review and revise as appropriate gender responsiveness of NDCs and NAP of Sri Lanka		Need for more gender sensitivity and gender-specific targets and actions
Need to enhance existing monitoring mechanisms and introduce new ones	Need to develop a detailed monitoring plan to track and report on NDC-NAP implementation progress at the national level	Lack of a comprehensive MRV mechanism for government, development partners, and private sector
Opportunity to leverage additional private sector funding and enhance public-private partnerships	Need to increase the private sector engagement and overcome barriers to investment	Need to recognize the roles and contributions of development partners and private sector
Need to develop an implementation and financing plan for NDC actions on national and local level	Need for financial and political support to ensure that NDC implementation measures can gain momentum	Lack of a detailed implementation and financing plan; opportunity to overhaul climate budget tagging to be more precise regarding local-level fund allocation
	Need to secure and promote transparency in administrative and implementation processes of NDC	
	Need to conduct an assessment of resource and capacity needs and mobilization of adequate resources	Need for concrete targets and associated monitoring and evaluation
		Need for more detailed indicators for forest restoration and conservation success
		Lack of a tangible target for emission reduction

TABLE 3. Identified gaps and needs for the implementation of NDCs on adaptation and loss and damage in Bangladesh, Nepal and Sri Lanka.

Key stakeholders shared it, that nonexistence of a mandate or a law that facilitates the implementation of NDCs has functioned as a cause for ineffective, and uncoordinated actions.

All three countries have also demonstrated the need for an MRV process for the implementation of NDCs on adaptation and loss and damage. The need for budget tagging, and sharing of the progress of NDC action in a publicly accessible system.

Capacity gaps have also been highlighted related to financial, technology, and technical expertise related to adaptation and loss and damage sectors. The government sector capacity building for developing project proposals to mobilise funding for adaptation and loss and damage actions, identification and application of suitable technologies, and the need for key expertise on NDC actions are among some of the capacity needed to be shared by the participants of the research.

Access to research, knowledge, lessons learnt has been also shared as a gap. The need to share scientific and evidence-based climate adaptation data, information and research have been noted. In addressing this gap and need, the research has developed an adaptation and resilience knowledge portal, that aims to provide needed information and research findings with different stakeholders working on NDCs on adaptation and loss and damage.

Need for regional collaboration for providing technical expertise, sharing of NDC progress was also noted. Development of common actions for adaptation and loss and damage related issues, as well as mobilising of climate finance at a regional level are options that remain to be explored to facilitate the effective implementation of adaptation and loss and damage NDCs.

4. CONCLUSION

NDCs form a key component of global and national level climate change actions. Being developing countries with low GHG emissions, Bangladesh, Nepal and Sri Lanka must focus on effective implementation of NDCs on adaptation and loss and damage. However, it is important to identify gaps and needs at the country level for the implementation of these actions. Initiatives such as policy gaps and needs analysis, interlinking with the 2020 NDC review process present opportunities for collaboration in addressing gaps and needs identified, as well as identifying alignment and synergies among key processes such as NDCs, NAPs, SDGs and the Sendai Framework are vital. Developing countries share common capacity gaps and needs, and also possess a wealth of information and experiences which could provide space for enhancing regional capacity and knowledge on the implementation of NDCs on adaptation and loss and damage. The research further will form the baseline for implementing capacity building activities on assessing climate risks, developing gender-responsive policies, plans and activities, enhancing the institutional and coordination mechanism at national and sub-national level for formulating and implementing adaptation plans and processes, and integrating climate change adaptation to the country's development processes.

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Integrating health into urban planning towards sustainability in Asian cities: Workshop summary

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ABSTRACT

The developing countries in Asia are going through rapid urbanization, and integrating health considerations in the early stage of urban planning is important for sustainable development. This project was aimed at capacity building of participants from developing countries in Asia to enhance their awareness on this topic, and to introduce assessment tools that are available to generate evidence that can inform public policymaking in urban planning. A total of 38 participants comprising academics, policymakers, practitioners and civil society from the Asian region attended the workshop. Issues on climate change and air pollution, and examples of good practices on physical activity promotion and mental health in the urban areas of Asian countries were presented. Collaboration across sectors and community engagement were emphasized in ensuring effective policy implementation. The assessment tools that were introduced included Health Impact Assessment (HIA), Low Carbon Living Co-benefits Calculator, Integrated Transport and Health Modelling, and Participatory System Dynamics thinking (PsD). The key concepts and data needed in the tool operations were explained. These tools need to be applied in the early decision-making phase to produce evidence that justifies the inclusion of health in policy later.

1. INTRODUCTION

Urban planning is a general term that can encompass several different fields in a city, depending on the contemporary needs of the respective country (Levy, 2017). From housing, town planning, landscaping, design, transport infrastructure, waste management, to biodiversity and forestry, agriculture, and disaster response, urban planning can have important implications across a country's economy, sustainability, resilience and human wellbeing (de Leeuw, & Simos, 2017; Levy, 2017). To that end, indicators have also been developed to measure a city's liveability such as safety, walkability, availability of public spaces, etc., which are closely related to many planning parameters (Badland et al., 2014; Pineo et al., 2018). For the present paper, we refer to urban planning as the planning of physically built environments in cities.

KEYWORDS

Developing countries, Health impact assessment tools, Participatory, Policy integration, Urban planning

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HIGHLIGHTS

- The workshop trained 38 participants from nine Asian countries.
- Guidelines and good practices for integrating health in urban planning were shared.
- Intersectoral and community engagement are essential for program sustainability.
- Low data quality may complicate the use of assessment tools in developing countries.

Following rapid urbanization worldwide, sustainable development has been a pivotal global change concept that is incorporated in the foundations of all urban governing sectors, including urban planning (Wheeler & Beatley, 2014). On the other hand, sustainable development and population health are mutually reinforcing elements in urban systems (Webb et al., 2017). Sustainable development promotes an environment that induces healthy behaviour, reduces population exposure to harmful environmental health determinants that are fundamental to disease prevention, and ensures a healthy population, which is the central driving force to the sustainable development (Acharya, Lin, & Dhingra, 2018).

Urban planning in relation to sustainability and public health has been studied extensively in the past two decades (Mueller et al., 2017). A large amount of evidence points out that urban design such as high density and mixed land use, together with transit oriented development (TOD) could create an enabling environment for reducing traffic emissions and increasing.

population physical activity through alternative transport (Stevenson et al., 2016). Early incorporation of health in urban planning, especially during the development phase as in the Asian low and middle income countries (LMICs), could avoid the need for costly transformative urban restructuring for health mitigation and adaptation later (Chan & Li, 2016). To facilitate policy integration from multiple government sectors in a holistic perspective, approaches such as co-benefits and Health in All Policies (HiAP) have also been introduced (refer to Box 1).

This paper presents a workshop summary of "Integrating Health into Urban Planning towards Sustainable Development Goals in Developing Countries" on the presentations conducted to enhance awareness and knowledge of integrated assessment tools that can facilitate the integration of health in urban planning, from policymaking to implementation.In public policy making, sustainability strategies are usually prioritized and carried out based on their socio-economic values and returns (Macmillan et al, 2014). In the Asian cities of LMICs, poor health information caused by lack of system infrastructure and training has rendered limited quantifiable health evidence that can be used to inform policies from the public health perspective (Walsham, 2019). Integrated health assessment tools are useful to facilitate measurements of health progress and subsequently, the impacts of potential development projects. This can be undertaken qualitatively or quantitatively and can enhance negotiations, and inform policy decision making (WHO, 2014). Established integrated health assessment tools that have combined reliable data such as standard emission factors and disease relative risks sourced from robust systematic reviews of studies in developed countries can bridge evidence gaps in developing countries, and facilitate the quantification of health impacts to be fed into the policymaking process. By identifying policies that may help or hinder their objectives, trade-offs can be minimized to achieve the most beneficial results from the limited resources in developing countries (Hutton et al., 2018).

Box 1. Definition of terms

- Sustainable development – "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations General Assembly, 1987, p. 43).
- Co-benefits – "The benefits of policies that are implemented for various reasons at the same time—including climate change mitigation—acknowledging that most policies designed to address greenhouse gas mitigation also have other, often at least equally important rationales (e.g. related to objectives of development, sustainability, and equity). The term co-impact is used in a more generic sense to cover both positive and negative side of benefits." (IPCC, 2001).
- Health in All Policies (HiAP) – "An approach to public policies across sectors that systematically takes into account the health implications of decisions, seeks synergies, and avoids harmful health impacts in order to improve population health and health equity." (WHO, 2014).

2. METHODOLOGY

A workshop on "Health in Urban Planning" was held at the University Selangor, Shah Alam Campus, Malaysia from 3-5 April 2019. There were 25 applicants from 17 cities and five local Malaysians who were screened and selected based on their background to join the workshop under the sponsorship of Asia Pacific Network for Global Change CAPaBLE Program (Box 2). The international participants were from Phnom Penh (Cambodia); Xiamen, and Guangzhou (China); Bathinda, and Gurgaon (India); Padang, Bangka, Andalas, Bandung (Indonesia); Vientiane (Lao PDR); Davao, Quezon City, Batangas (Philippines); Bangkok and Ayutthaya (Thailand); Hanoi and Ho Chi Minh (Viet Nam) (Figure 1). Other local participants included two staff from the Ministry of Health Malaysia, a representative from Kuala Lumpur City Hall, and five academics from University Selangor.

Box 2. Asia-Pacific Network for Global Change Research's CAPaBLE programme (APN, 2020) aims to:

- "enhance the capacities of scientists, policy-makers and other relevant stakeholders in the Asia and Pacific region to identify and assess global change issues at local, national and regional levels", and
- "identify appropriate solutions to resolve the issues and achieve sustainability".

FIGURE 1. Workshop participants and speakers.

FIGURE 2. Topics of invited presentations from each country.

Besides, 10 local and international experts on urban planning, environmental health, and sustainability from Kuala Lumpur, Jakarta, Bangkok, Sydney, Melbourne, Christchurch, Dunedin, Tokyo, and Cambridge were invited as speakers (Table 1). The speakers were invited based on their expertise and experiences in urban planning and health (No.1-7), and the application and development of tools for integrated assessment and decision making (No. 8-11) (Figure 2).

The workshop participants consisted of academics, policymakers, practitioners and a media reporter to have representatives of different roles in the workshop. The backgrounds of the participants included environmental science, public health, urban governance, climate change, urban geography, hydrology, urban ecology, disaster rehabilitation, health systems, and economy. Such diversity complemented the need for interdisciplinary and intersectoral communications in tackling planning in the complex urban systems in developing countries.

3. RESULTS AND DISCUSSION

3.1 Urban sustainability, health and urban planning good practices

Climate change and air pollution are the most common topics that are being emphasized in many urban sustainability discussions as the emissions of greenhouse gas often come together with air pollutants such as particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbons (HCs) emissions from sources such as power plants and vehicle tailpipes (Driscoll, Stettler, Molden, Oxley, & ApSimon, 2018; Winkler et al., 2018). Air pollution is known to have caused a high burden of diseases, especially from cardiovascular and respiratory diseases. Based on the IPCC report, urban areas accounted for 67-76% of energy use and three-quarters of carbon emissions globally (IPCC, 2014). As urban growth accelerates, especially in Asian megacities, urban areas become the focus for mitigating carbon and air pollutant emissions through urban infrastructures that shape the energy use patterns in human and transport activities (Creutzig, Baiocchi, Bierkandt, Pichler, & Seto, 2015).

Non-communicable diseases (NCDs) accounted for 71% (41 million people) of global mortality in 2016, mainly from cardiovascular diseases, chronic respiratory diseases, cancers and diabetes (Bennett et al., 2018). In particular, a large proportion of preventable premature mortality from NCDs (40%) was contributed by the low and middle income countries, including Southeast Asia (Martinez et al., 2020). Although the risk factors for

	Theme	*Presenter/affiliation*	*Presentation*
1.	Empirical knowledge and good practices	Jamal Hisham Hashim, Universiti Selangor, Malaysia	Urban Health Issues in Malaysia
2.		Hj Ihsan Zainal Mokhtar, Malaysian Institute of Planners, Malaysia	Integrating Health Concept into Urban Planning in Malaysia
3.		Budi Haryanto, Research Center for Climate Change, University of Indonesia, Indonesia	Climate Change and Air Pollution: Health Impacts and Alternative Control Strategy
4.		Piyawat Katewongsa, Institute for Population and Social Research, Mahidol University, Thailand	The situation of physical activity promotion and built environment in Thailand
5.		Anna Stevenson, Canterbury District Health Board, Christchurch, New Zealand	Determinants Led Planning in Practice
6.		Alice Covatta, The Architecture and Urban Design at co+labo, Keio University, Tokyo, Japan / The Centre for Urban Design and Mental Health	Density and Intimacy in Public Space: a case study of Jimbocho, Tokyo's book town
7.		Susan Thompson, City Futures Research Centre, University of New South Wales, Australia	Healthy Built Environments in Action! Experiences in policy and practice implementation
8.	Assessment tools	Jamal Hisham Hashim, Universiti Selangor, Malaysia	Health Impact Assessment as a Planning and Decision-Making Tool
9.		Jason Thompson, Melbourne School of Design, University of Melbourne, Australia	The Development of A Low-Carbon Living Co-Benefits Calculator
10.		James Woodcock, MRC Epidemiology Unit, University of Cambridge, United Kingdom	Modelling Transport Related Health Effects in Low and Middle Income Countries (LMICs)
11.		Alexandra Macmillan, Department of Preventive and Social Medicine, University of Otago, New Zealand	Using Systems Thinking and Modelling to Support Decision-Making for Healthy Sustainable Cities

TABLE 1. List of invited presentations.

NCDs are well established, a review of evidence identifying the targeted reduction of NCD risk factors to impact on several NCDs simultaneously found that the improvement of physical inactivity, diet and air pollution have the strongest protective effects across cardiovascular diseases, cancer, diabetes, and dementia (Peters et al., 2019). These risk factors could be addressed in effective public policies and health interventions to reduce the number of preventable premature mortality (Martinez et al., 2020).

Urban planning can serve as an effective intervention to reduce the risk factors of NCDs by creating contextual defaults that empower behaviours to benefit both health and the environment (Frieden, 2010). Placed in the second tier of the Health Impact Pyramid (Figure 3), urban planning can affect human health and well being at the population level through the provisions of a clean environment and infrastructure. Table 2. shows the extraction of contents on good practices from the workshop presentations. These good practices and approaches could be useful guiding principles in building healthy cities, by integrating various health determinants including physical and mental health in urban planning related policies, funding allocations, implementation strategies, and community empowerment programs.

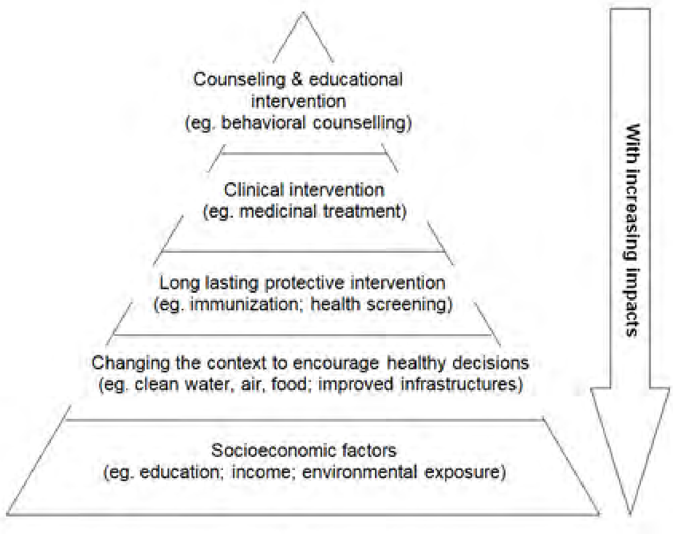

FIGURE 3. Health impact pyramid in public health interventions (Frieden, 2010).

	Theme (country)	*Key points and good practices*
1.	Determinants led planning (Christchurch, New Zealand)	» Ensure greater Christchurch liveability through leadership, partnership, resilience, innovation, integration, regeneration, equity » Health Impact Assessment to mainstream health in planning with evidence » Integrated Planning Guide For Health, Sustainability And Resilience (Community and Public Health, 2019) » Examples of good practices: → 2007 Greater Christchurch urban development strategy • Prepared in response to projected population growth • Voluntary partnership of city, district, environment agency, transport agency • Clear direction for resource management plan • Develop significant public interest and momentum » Our Space (2018-2048) (http://greaterchristchurch.org.nz/background/our-space/): planning for future housing and business development and capacity » Health policy: Take Care New York 2004 (Frieden, 2004) to prioritize on leading preventable cause of illness and deaths » San Francisco Burden of Disease & Injury Study: Determinants of Health (http://www.healthysf.org/) as a resource for guiding development » Health in All Policies: working across sectors and communities on public policies through partnership with key stakeholders (Canterbury Health in All Policies Partnership (CHIAPP)) » Community development based on DEET: determinants, equity, evidence, treaty of Waitangi (3 principles: partnership; participation; protection)
2.	Integrating health in urban planning (Malaysia)	» Essentials to healthy built environment: → Access to quality foods → Safe and affordable public transport → Pedestrianized road and cycling network → Efficient waste management → Access to natural environment » Strategies: → Efficient funding and investment of facilities → Improve the use of existing resources such as transformation of abandoned parking lots, and dilapidated street corners, and public sharing of school fields → Placement of schools, community spaces, and facilities within walking distances » Examples of good practices (Edwards & Sauros, 2008): → Walking school buses in Rome, Italy under collaborations of school authorities, parents, police, district and road safety officers → Regeneration of Admiral Park in Liverpool, UK with the involvement of local school children → Greenbelt around the city of Milan, Italy which connects the parks and form green corridors to the inner city → Transformation of a back lane to community garden especially for older people in Shah Alam, Selangor Malaysia

TABLE 2. Key points and examples of good practice from workshop presentations.

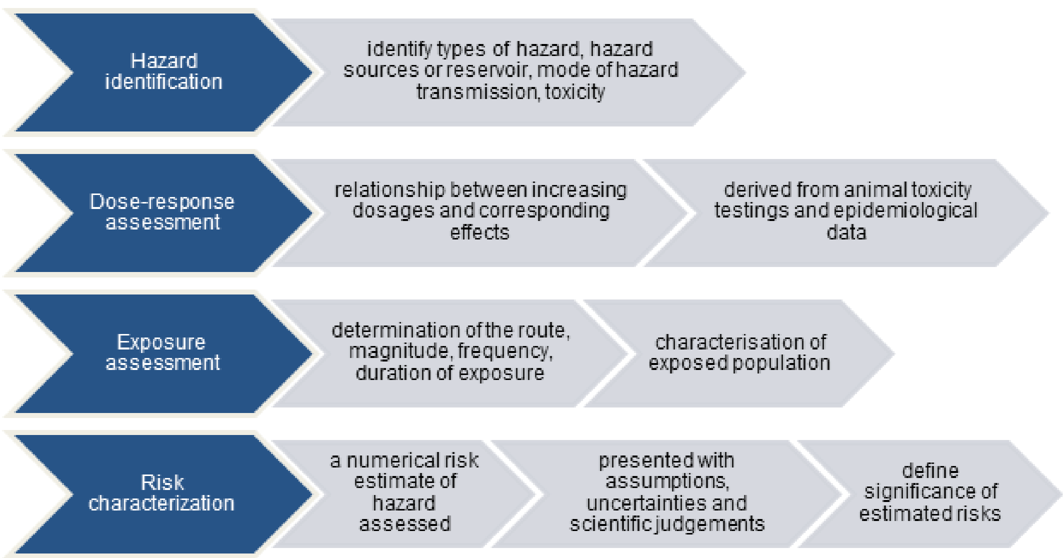

FIGURE 4. Steps in Health Impact Assessment (Department of Environment Malaysia, 2012).

	Theme (country)	Key points and good practices
3.	Experiences in policy and practice implementations (Australia)	» A safe city is a healthy city » Guidelines to shade from the sun (http://www.webshade.com.au/) are essential to support physical activity in Australia » Fall prevention strategies to create an age-friendly built environment for health and safety across life course » Strategic communications to practitioners through journals » Incorporating health in federal policies » 3 key domains of built environment and health: → Getting people active (footpath, bike path, open spaces) → Connecting and strengthening communities (community gardens) → Providing healthy food options (retain prime agricultural land close to cities) » Engagement of multi-sectors, researchers, practitioners, and community is essential. » Example programs: → A bountiful harvest: Community gardens and neighbourhood renewal in Waterloo (Bartolomei, Corkery, Judd, & Thompson, 2003): gardens are important for physical and mental health → Men's Shed (https://mensshed.org/): a community program that encourages men's involvement in community projects to improve social well being → Cool Streets (https://www.coolstreets.com.au/): an initiative to empower communities to cool the streets → Cooling the City Strategy (Penrith City Council, 2015): response to urban heat through community engagements and stakeholder partnerships → Think city (https://thinkcity.com.my/): a Malaysian organization that works on place-making and urban rejuvenation (e.g. George Town, Penang)
4.	Built environment and physical activity (Bangkok, Thailand)	» Major issue: to ensure good conditions of bike and walk lanes, playground » Active place targets: → To increase access and affordability of public space for low income communities → To transform unused/wasteland to healthy open space for all population → To expand healthy city models to other cities outside Bangkok » Example projects in Bangkok, Thailand: → Transformation of Lumpini park by closing off the roads inside the park from vehicle traffic → Transformation of space under expressways to recreational and cycling space, especially for the use of the low income community (air and noise pollution mitigated by increased tree planting) → Design of activities at the community space by engagement of parents, children, and elderly to understand their needs and wants (interactive learning through actions) → Transformation of old buildings near Chinatown to museum and learning centres → Skywalk connecting shopping malls within the city centre of Bangkok → Bike city project to increase biking in the city → GoodWalk project at Thong Lor-Ekkamai and Ari-Pradiphat, and Klong San (Wancharoen, 2018) → To improve walkability and connectedness of areas → To boost sales of shops along the routes → To improve physical and mental well being of residents » Future Plan: Transformation of the riverfront of Chao Phraya River by increasing walkability and participation of community activities » Collaboration and partnerships with civic groups, and active participation of the community by giving information about the projects, and community leadership are key to the sustainability of projects
5.	Mental health: Density and intimacy in public space (Tokyo, Japan)	» Environmental factors to mental health: → Overstimulated public space (noise, sights, smell, crowding) → Diminished protective factors (exposure to nature and exercise) » Extreme intimate space within highly dense areas (Tokyo): e.g. Love Hotel, Manga Kissa, Karaoke Box » Space connected to every transport station has its own subculture created by the local community » Case study of Jimbocho, Tokyo's book town's design for intimate reading space for mental health (Covatta, 2017): → Bookshop layout allows people to read inside and outside of shops → Shops can accommodate no more than four people → The layout of book racks allows flexible browsing of the books → Decoration of book shops based on the unique taste of bookshop owners → Parasite economy grows around the bookshops, e.g. eateries and coffee shops customized for reading → People develop personal routes around the book shops area → People of all social levels and backgrounds can visit the area » Urban design action points: → Facilitate social interaction while considering privacy → Compact and walkable neighbourhoods with mixed land use to encourage natural interactions → Multilayered street fronts for flexibility of visitors → Space for community participation and volunteering, e.g. street benches, chess tables

TABLE 2 (cont.). Key points and examples of good practice from workshop presentations.

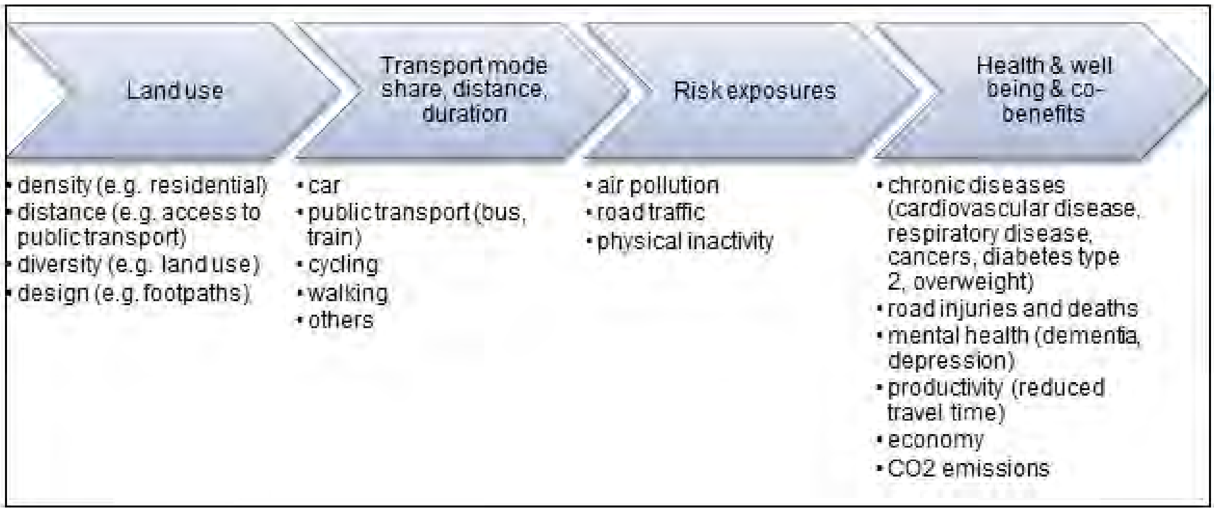

FIGURE 5. Data inputs and flow of connections between factors in Low Carbon Living Co-Benefits Calculator (Stevenson and Thompson, 2019).

3.2 Tools

3.2.1 Health impact assessment (HIA)

Health impact assessment (HIA) is a combination of procedures, methods and tools that are used to estimate the potential impacts (physical, chemical, biological, social) on a specified human population system under a specific set of conditions (a policy, program or a project) within a certain timeframe (enHealth, 2001). It is useful to inform and influence decision making by weighing in the evidence of health impacts from alternative development plans (Lock, 2000). In Malaysia, HIA is mandatory for many detailed Environmental Impact Assessment (EIA) project under prescribed activities. Figure 4 shows the steps involved in the HIA guidance document of Malaysia (Department of Environment Malaysia, 2012). An example of HIA application was given on the case of Kim Kim River in Pasir Gudang, Johor, where toxic chemical dumping (hazard identification) caused elevated levels of methane, benzene, and acrylonitrile (dose-response assessment) in the river, and hospitalization of poisoned victims among school children (exposure assessment) ("Pasir Gudang chemical spill", 2019).

3.2.2 Low carbon living co-benefits calculator

The model was built on the deterministic model of compact cities and health model connecting land use, transport mode, risk exposures and health outcomes (Stevenson et al., 2016) (Figure 5). Using 1.2 million of household land parcels with specific land use variables from the Australian Urban Research Infrastructure Network (AURIN), counts of features such as household density, public transport stops, number of intersections were captured. These variables were then used to develop a set of regression equations with the data of socio-demography, economy, productivity, and health from the Department of Health and Human Services Victorian Population Health Survey to estimate the co-benefits (Stevenson & Thompson, 2019). On the website interface of the calculator (https://thud.msd.unimelb.edu.au/), data can be input directly to generate performance outputs such as BMI and life satisfaction based on land use clusters. Although this tool applies in the Australian context, it presents a useful example of the methods and data needed to calculate co-benefits of specific land use planning in other cities.

3.2.3 Integrated transport and health impact model

Compared to the low carbon living co-benefits calculator, the model emphasizes on estimates of health impacts from different transport scenarios through distinctive models for air pollution, injuries and physical activity (Woodcock, Givoni, & Morgan, 2013). The primary data are from travel surveys, physical activity surveys (for non-travel physical activity), and police records of injury. In order to be a globally applicable tool, prototype models are being tested in countries such as India, Latin America and Africa with different traffic mix and background air pollution, injury and physical activity levels (Sá et al., 2017). In this model, both ambient and mode-specific in-vehicle exposure of air pollution are accounted for in the dose-response relation to health outcomes (Cepeda et al., 2017). The risks of traffic injuries are calculated by accounting for vehicle modes and distance travelled by both victims and vehicles. Previous studies have shown that the largest benefits can be reaped from the increase in physical activity (Mueller et al., 2015). For modelling scenarios in low and middle income countries, the challenges lie in the quality of data such as injury records and underreporting of short trips in travel surveys, which make uncertainty analysis important. Thus, a new method of data collection, such as using Google Street View, is being developed (Goel et al., 2018).

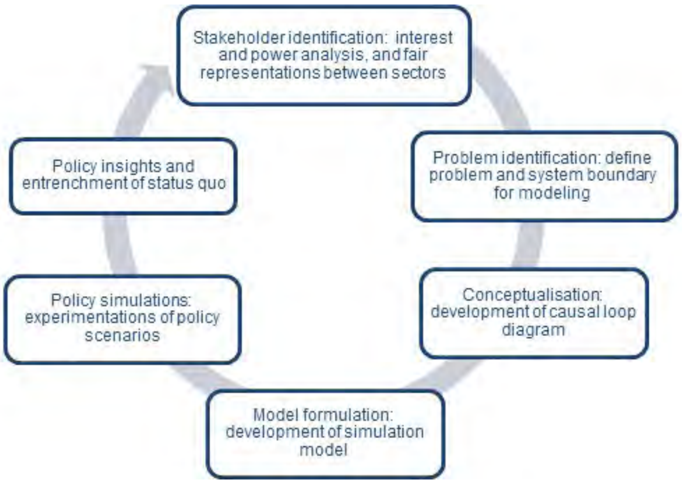

FIGURE 6. Process of participatory systems dynamic modelling (Macmillan et al., 2016; Videira et al., 2017).

3.2.4 Participatory systems dynamic modelling (PsD)

Participatory systems dynamic modelling (PsD) is a method that aims to bring changes both at the policy and the ground level through a shared learning process involving stakeholders from all relevant sectors (Macmillan et al, 2014). It facilitates understanding of the endogeneity in a complex system through feedback loops, stocks and flows process, and ensure fair representations of various sectors in public policy decision making (Eker, Zimmermann, Carnohan, & Davies, 2017). However, this process needs to take place in the early stage of policymaking; particularly at recognizing the problem to justify the inclusion of health in policy in the later stage (Macmillan et al., 2016). Figure 6 shows the general process of PsD.

4. CONCLUSION

In conclusion, the workshop has achieved the objectives of increasing awareness and introducing the policy assessment tools for integrating health in urban planning among the 38 international workshop participants from the Asian region. The workshop has clearly demonstrated that urban planning has great influence in determining population health, and the sustainability of cities through air quality, traffic, active living, and a population's well being. Given the complex relationships between the environmental and health determinants in cities, the integrated health impact assessment tool, carbon calculators, and system thinking are tools that could be used to layout a clearer picture of the co-benefits of healthy urban planning with a scientific basis, and for lobbying urban planning policies that are supportive of the development of a healthy and sustainable environment for the citizens. Besides, the workshop has provided many guidelines, good practices and examples of management and implementation strategies extracted from both developed and developing countries for the reference of city planners. These examples show that the local cultures and experiences also need to be considered when incorporating health aspects in urban plans. Therefore, it is important to consult multiple stakeholders, including the local community, with a participatory approach to ensure that the programs that are carried out are sustainable to the future by themselves. In an additional note, the availability of reliable data is vital to be able to employ the assessment tools with confidence in cities, especially of developing countries where data is often lacking. These tools need to be employed early in the policymaking process to give the most significant effects. Therefore, further studies on how to utilize these tools in practice with the available data need to be explored for the planning of cities in the developing countries.

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Towards a scientific-based farming of sea urchins: First steps in the cultivation of *Diadema setosum*, *Diadema savignyi* and *Mesocentrotus nudus*

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ABSTRACT

Fishing or breeding. This question arose relatively recently, but in the last decade, mankind will have to lean more towards the second. Sea reserves of useful species are exhausted. One possible solution to this problem is marine farming. We proposed to investigate the larval development of three sea urchin species: *Diadema setosum* (Leske, 1778), *D. savignyi* (Audouin, 1829) (South China Sea), and *Mesocentrotus nudus* (A. Agassiz, 1864) (Japan Sea). The larvae of *Diadema setosum* and *D. savignyi* were very similar, and some differences could only be observed at the late pluteus stage. These sea urchins were developed through the modified pluteus, which only had two pairs of larval arms. The arms were very long—in *D. setosum* above 2 mm, and in *D. savignyi* about 5.5 mm. Larval development took about 45 days in *D. setosum* and 47–50 days in *D. savignyi*. In contrast, *Mesocentrotus nudus* (A. Agassiz, 1864) was developed through the pluteus larvae, which had some differences from the pluteus of the genus Strongylocentrotus. Their dimensions did not reach one millimetre. The larval development of *Mesocentrotus nudus* lasted about 30 days. Analysis of material and time costs has led to the conclusion that *Mesocentrotus nudus* is the most convenient for obtaining seed material. However, this species cannot be used for the tropical zone. The results of *D. savignyi* and *D. setosum* can be used to increase the number of cultivated species.

KEYWORDS

Diadema savignyi, Diadema setosum, Larval culture, Larval development, Mesocentrotus nudus

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1. INTRODUCTION

The global trend of aquaculture development gaining importance in total fish supply has remained uninterrupted. In 2012, farmed food fish contributed 42.2% of the total 158 million tonnes of fish produced by capture fisheries (including for non-food uses) and aquaculture. This compares with only 13.4% in 1990 and 25.7% in 2000 (FAO, 2020). In 2016, global aquaculture production (including aquatic plants) was 110.2 million tonnes, with the first-sale value estimated at USD 243.5 billion. In 2018, the aquaculture production volume was about 938,500 tonnes of aquatic animals (USD 6.8 billion) such as turtles, sea cucumbers, sea urchins, frogs, and edible jellyfish (FAO, 2018).

Sea urchins are not only a source of high protein delicacy food but are also a potential source of biological active substances used for medical purposes (Rahman, Arshad, & Yusoff, 2014). Harvesting of natural sea urchins has possibly reached its limit, and thus, it is likely that the global production of sea urchin roe from wild fisheries will decline (Rahman et al., 2014). In recent years, a central circle of countries comprising producers and suppliers of products from sea urchins to the world market has been developed (Stefansson, Kristinsson, Ziemer, & Hannon, 2017). For further sustainable development, scientific studies of the biological principles of reproduction of mariculture objects must be introduced.

Countries in the Asia-Pacific region with a high

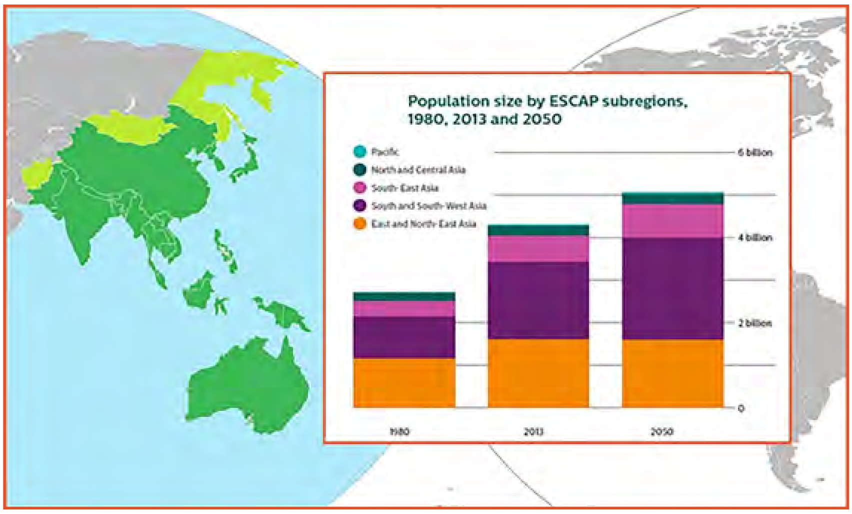

FIGURE 1. Asia-Pacific region and its population dynamics (UN Economic and Social Commission for Asia and the Pacific (ESCAP), 2014).

population are experiencing problems of a lack of protein-rich food. Sustainable development of coastal countries can be established by linking their economies with sea resources (Figure 1).

Resources from the sea in the region are not only fish but also invertebrates, which diversify our food resources. In recent years, the problem of overfishing of aquatic biologic resources has become acute. The solution to this problem requires strict compliance with the catch rates regulations and the development and application of methods for artificial cultivation of aquatic objects. Science-based approaches can enhance farming techniques, and one such approach is the development of coastal mariculture to reproduce commercial species using sophisticated technology. Along with the creation of marine aquaculture farms using traditional objects, like oysters, sea urchins, sea algae, et cetera, it is necessary to study the reproductive characteristics of other common species. Marine objects may have been the earliest food objects for humans. Evidence is provided by the so-called kitchen heaps, which were found at the sites of ancient people located on the sea coast. Analysis of the spectrum of food habits of ancient man shows that sea urchins made up a significant part of the diet of people. Since ancient times, sea urchin gonads are culinary delicacies in many parts of the world. Sea urchin roe is considered as a prized delicacy in Asian, Mediterranean and Western Hemisphere countries and has long been a luxury food in Japan. Sea urchin mariculture, together with other farmed animals, is of growing importance in such a situation.

The goal of the study was to present comparative data on reproductive characters of three common species of sea urchins. Marine aquaculture is one way to meet the growing demand for healthy marine food. To date, there are no cost-effective technologies for growing sea urchins in aquariums. Some countries obtained wild seed materials for further cultivation up to commercial size in suitable water areas (McBride, 2005). In both cases, knowledge of the embryonic and larval development of target species of sea urchins may be in demand.

Choosing species for possible cultivation, we drew attention to sea urchins, which are common and in consumer demand, although poorly investigated in terms of the biology of their embryonal and larval development. Our study focused on two species of Diadema, which are widely distributed on the coast of Viet Nam and many other areas in the Indo-Pacific. These species are in demand, and we witnessed this in the vicinity of the Viet Nam towns, like a Nha Trang.

Mesocentrotus nudus was selected as it is especially loved in Japan, the primary consumer of sea urchin uni. This is also a common species on the coast of Russia's Primorsky Region. While Strongylocentrotus intermedius has been cultivated for quite some time in mariculture farms in Primorye, *Mesocentrotus nudus* has not yet been maricultured.

Diadema setosum (Figure 2(A)) and *D. savignyi* (Figure 2(B)) are common species in the South China Sea, and they inhabit similar biotopes (Liao & Clark, 1995). In Viet Nam's coastal waters, these species are distributed around rocky and stony substrata at the upper layers of the sublittoral zone. Sea urchins with long thin spines can cause harmful stings, and they have so far retained their numbers and form dense mixed groups on stony bottoms, and climbing into deep crevices between large stones.

The larvae of Diadema are remarkable in planktonic populations. Those of *D. setosum* were described by Mortensen (1921, 1931, and 1937) and more recently by Rahman, Yusoff, & Arshad (2015) from Malaysia and Dautov and Dautova (2016) from Viet Nam.

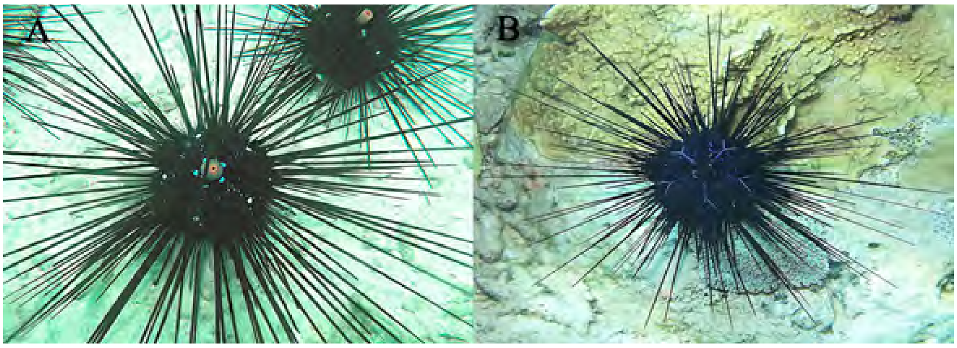

FIGURE 2. (A) *Diadema setosum* (Leske, 1778). (B) *Diadema savignyi* (Audouin, 1829).

FIGURE. 3. Sea urchin *Mesocentrotus nudus* (A. Agassiz, 1864).

The distinctive features of adult *D. setosum* and *D. savignyi* are obvious (Figure 2). *D. setosum* has five white spots at the aboral side, orange rim around the anus, and chains of blue points on the test surface along the ambulacra (Figure 2(A)). On the other hand, *D. savignyi* has a set of characteristic blue lines at the aboral side, and a dark blue rim around the anus (Figure 2(B)). The morphology of their larvae (Dautov & Dautova, 2016) and the longevity of the larval development were investigated (Rahman et al., 2015). Here we present the original account of the larval common structure of *D. savignyi*, and for comparison, we present data on the development of the similar sea urchin *D. setosum*, both of which are from the Nha Trang Bay of the South China Sea.

Sea urchin *Mesocentrotus nudus* (A. Agassiz, 1864) inhabits the Japan and Yellow seas. Outwardly, this sea urchin looks somewhat like diadematids—black and armed with spines about 3-4 cm in length (Figure 3). *M. nudus* larval development was investigated in Japan waters (Kawamura, 1970). However, the area of the species is wider in the Asia-Pacific. The data on the larval development of *M. nudus* collected at the coast of Primorye region (Peter the Great Bay, the Sea of Japan) is presented here, for comparison.

Our interest in *Diadema setosum*, *D. savignyi* and *Mesocentrotus nudus* was initiated by the lack of information about larval development and schedule of the development of these species. At the same time, these are common species in the region—*D. setosum* and *D. savignyi* in the tropical Indo-Pacific, and *Mesocentrotus nudus* in the Japan and Yellow seas. These species are consumed by the citizens of Japan and local aboriginal communities in Southeast Asia countries. Moreover, *Mesocentrotus nudus* known as the former *Strongylocentrotus nudus* is very popular in Japan.

2. METHODOLOGY

2.1 Cultivation of larvae in the laboratory

2.1.1 Sea urchins of genus Diadema (Diadema setosum (Leske, 1778) and Diadema savignyi (Audouin, 1829))

The investigation of the larval development of *Diadema setosum* and *D. savignyi* was carried out in April-July, from 2014 to 2016. The work consisted of the following steps:

- *Collecting adult sea urchins.* Adult and mature sea urchins of *Diadema setosum* and *Diadema savignyi* with a test diameter of about 60-70 mm were collected in Nha Trang Bay (South China Sea) by skin divers. In the laboratory, sea urchins were maintained for 2-3 days in tanks with running seawater (t° = 28-29°C) until spawned. About 50-60 specimens of both species were used. They were unfed in the laboratory.
- *Water preparation.* Filtered seawater (FSW) was obtained by filtrating through 0.4 μm filters. The volume of FSW used depends on the frequency FSW in jars containing the larvae (twice a day).
- *Obtaining gametes.* To obtain gametes, long spines were trimmed off and sea urchins were placed mouth upward, and gonopores downward on glass cups with FSW. Spawning was induced by injecting 0.2-0.5 ml of 0.55 M KCl solution through the peristome (Iwata & Fukase, 1964). Spawning females remained in the glass cups, shedding eggs into the FSW. Sperm from males were collected in Petri dishes (dry sperm) and placed in a refrigerator until used. After shedding gametes, sea urchins were released back to the sea. For artificial fertilization, eggs from 3-4 females and semen from 3-4 males were used.

- Shaded eggs from 3-4 females (approximately 10-12 million eggs) were washed three times with FSW, placed in a thin layer on the bottom of a 2-litre cup containing FSW, and fertilized by adding 5-6 drops of a freshly prepared suspension of spermatozoa (20 μl dry semen diluted in 60 ml of FSW). Samples of the eggs were taken periodically after insemination to confirm successful fertilization by checking under a compound microscope. The zygotes developed their fertilization membrane at 20-40 minutes after fertilization. Further, the zygotes were washed three times in FSW and left in the same cup until the swimming blastula stage.
- *Cultivation of larvae.* The next day, larvae in the stage of swimming blastula were transferred to 4-litre glass cans with a density of 2-3 larvae per ml, in which they were cultured according to Strathmann (1987), with permanent agitation of seawater until the larvae had settled and metamorphosed. The temperature in the room was 27-28°C. By reverse siphon, about 90% of the water was changed twice a day – in the morning at 6:00 and in the evening at 18:00. Preliminary experiments indicated that changing seawater twice a day was required for normal development of larvae at 27-28°C. The larvae were fed on the unicellular algae Nannochloropsis oculata. Food was added during every water changing with an approximate concentration of 2000-3000 cells/ml. Several larval cultures were initiated during our investigation – one in 2012, six in 2013, and six in 2014 for *D. setosum*; and eight in 2015, and three in 2016 for *D. savignyi*. Each culture consisted of 12 4-litre cans with a density of 2-3 larvae per 1 ml.
- *Analysis and photoregistration.* About 20 larvae were measured and photographed daily in the early stages (from 1 to 10 days). During 10 to 40 days of cultivation and before larval settlement, 2-5 larvae were taken for analysis two times a week. They were examined, photographed and returned to culture dishes. Live embryos and larvae were observed under a compound microscope. Larvae were photographed with a digital camera by putting the camera lens to a microscope eyepiece with an ocular micrometre. The size of eggs, embryos, blastulae and larvae were measured from the photo images. Sizes are given as mean value (MV) ± standard deviation (SD). In the late plutei of *D. setosum* and *D. savignyi*, the entire larvae with arm lengths greater than 2 mm did not fit within the field of view even with the smallest magnification lens. Their arm lengths were measured using panoramic photos with images combined and enhanced in Adobe Photoshop CS6 8.1 6.3.9600.17415 (Adobe Systems Software Ireland Ltd., 6 Riverwalk, Naas Road 24, Dublin, Ireland).

2.1.2 Sea urchins of genus Mesocentrotus (Mesocentrotus nudus (A. Agassiz, 1864))

For the investigation, the adult sea urchins *Mesocentrotus nudus* (A. Agassiz, 1864) from Vostok Bay (Sea of Japan) were used.

- *Collecting adult sea urchins.* Skin-divers collected mature sea urchins at the reproductive season (July-September 2007). In the laboratory, sea urchins were placed in baths with running seawater until the experiment. During the investigation, 60 specimens of nudus were used with diameter of 60-80 mm. The sea urchins were returned to the sea after shading of gametes.
- *Preparing FSW*. Seawater was filtered through three layers of fine gravel and sterilized by water running under ultraviolet (UV) rays from quartz lamps (Dautov & Kashenko, 2008).
- *Obtaining the gametes*. Gametes were obtained by standard methods. Sea urchins were placed mouth up on to glasses with FSW and spawning was induced by injection of 0.2 ml of 0.55M KCl solution through the peristome (Iwata & Fukase, 1964). Spawning animals remained in the glass caps, shading gametes into FSW. Petri dishes with sperm from males were placed in a refrigerator until required.
- Eggs from three females and sperm from three males were used for artificial fertilization. Shaded eggs were washed several times in FSW and placed in a thin layer at the bottom of a 4-litre cup with FSW. Five to six drops of a freshly prepared suspension of spermatozoa that looked somewhat opalescent were added to eggs. The success of fertilization was checked under a compound microscope. The zygotes developed their fertilization membranes at 20-30 minutes after insemination. Further, the zygotes were washed three times in FSW and left in the same cup until the swimming blastula stage.
- *Cultivation of larvae*. The next day, larvae in the stage of swimming blastula were transferred to 5-litre glass jars with a density of 5–6 larvae per ml. After the larvae had attained the 4-armed pluteus, they were fed with equal parts of three algae: Nannochloris maculata, Isochrysis galbana and Chaetoceros muelleri. Each alga made up one-third of the total concentration

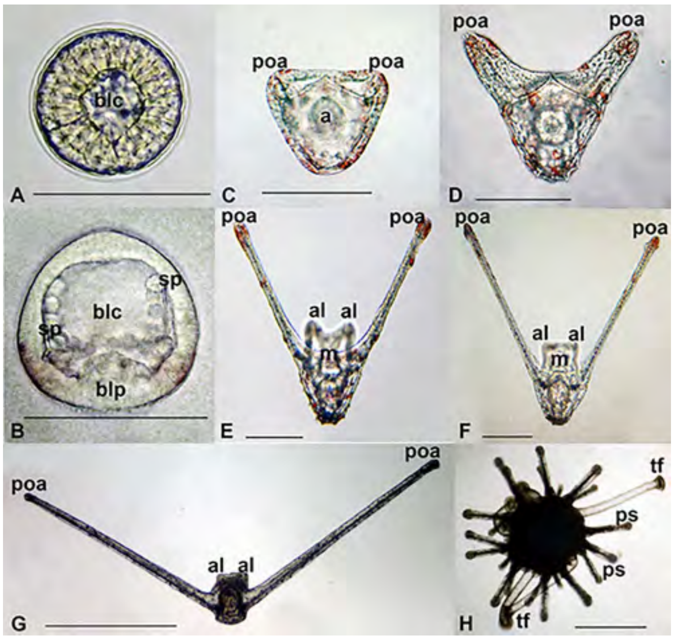

FIGURE 4. Larval development of Diadema setosum (Leske, 1778). (A) Early blastula stage with a small blastocoel (blc). (B) Larva at the beginning of the gastrulation with spacious blastocoel (blc) with primary skeletal spicules (sp) and the initial stage of the blastopore (blp). (C) Prism. Larva has two postoral arms (poa) and anus (a) but not mouth. (D) Pluteus with two arms (poa). (E) Pluteus with four arms. al – anterolateral arms, m – mouth, poa – postoral arms. (F) Pluteus 6 days old. al – anterolateral arms, m – mouth, poa – postoral arms. (G) 30-day-old pluteus. al – anterolateral arms, poa – postoral arms. (H) Juvenile of *D. setosum*. ps – primary spicules, tf – tube feet. Scale bar: (A), (B), (C), (D), (E), (F) – 100 µm, (G) – 1000 µm, (H) – 500 µm.

of 5,000-7,000 cells per ml, i.e. approximately 1,700-2,300 cells per ml. At the 6-armed pluteus stage (6-7 days after fertilization (a.f.)), we added two more algae Phaeodactylum tricornutum and Dunaliella salina to the feed mixture. The total number of algae remained the same – 5,000-7,000 cells per ml, and all five algae had an equal proportion – i.e. the concentration of alga species in the feed mixture was 1,000-1,400 cells per ml.

» *Analysis and Photoregistration*. A Reichert Polivar microscope with a Canon PowerShot S40 digital camera and a Leica DC 150 camera adapter were used to observe and register the development of the larvae. For measurements and observation, 20 larvae were taken from cultural jars the next day.

For image processing and preparation of the pictures, Adobe Photoshop CS6 8.1 6.3.9600.17415 (Adobe Systems Software Ireland Ltd., 6 Riverwalk, Naas Road 24, Dublin, Ireland) was used.

3. RESULTS

3.1 Larvae of the sea urchins family Diadematidae Gray, 1855

3.1.1 Diadema setosum (Leske, 1778)

Diadema setosum (Leske, 1778) developed from small isolecithal eggs with a diameter of 84.2 ± 3.1 µm (n = 25). Embryonic development took about 6.5-7.0 h and finished when a blastula left the fertilization envelope and became a larva (Dautov & Dautova, 2016).

Young rounded blastulae (Figure 4(A)), which swam around their longitudinal axis, gradually changed body shape. The late blastula just before gastrulation became elongated and had a narrow anterior tip (length 95.0 ± 1.7 µm, width 88.2 ± 1.7 µm (n = 14)), and they developed the first pigment cells. The first mesenchymal cells were visible in the narrow blastocoel. Then the blastoderm became thinner, the blastocoel more spacious, and the sclerenchyma produced primary spicules (Figure 4(B)). The blastula became a prism at the beginning of the invagination (Figure 4(C)). The width of the young prism (106.3 ± 2.0 µm) was greater than its length (88.2 ± 1.7 µm (n = 21)). The first pigment cells had appeared at this stage. At 23 h a.f., a prism developed; at 44 h a.f., a pluteus with one pair of arms had appeared (Figure 4(D)); at 45 h of development, plutei had two pairs of arms. The pigment cells coloured the pluteus of *D. setosum* dark red (Figure 4(E)). Six-day old pluteus had grown its arms (Figure 4(F)). The postoral arms of plutei grew to 1900 µm or more during further development (Figure 4(G)). Metamorphosis took place over 40-45 days. At this time, five primary ambulacral podia were visible within the larval body. The duration of metamorphosis from the moment of larval settlement until the juvenile sea urchins began to move along the bottom was 40-60 min. The diameter of the newly metamorphosed juvenile sea urchins was about 500 µm (Figure 4(H)).

D. setosum refers to sea urchins with small eggs. Fecundity of these urchins was about 4-5 million eggs. A high natural loss occurred during the cultivation of sea urchin larvae. Some embryos developed abnormally and did not turn into larvae. The development of larvae occurred at different rates. Many larvae became retarded in development so much so that even after 40-50 days of development, they remained at the stage of early pluteus. The percentage of metamorphosed was 0.0042% (0.0014% – 0.0052%), and this was calculated as the number of juvenile sea urchins to the total number of larvae in the culture.

3.1.2 Diadema savignyi (Audouin, 1829)

The gametes obtained from the females *Diadema*

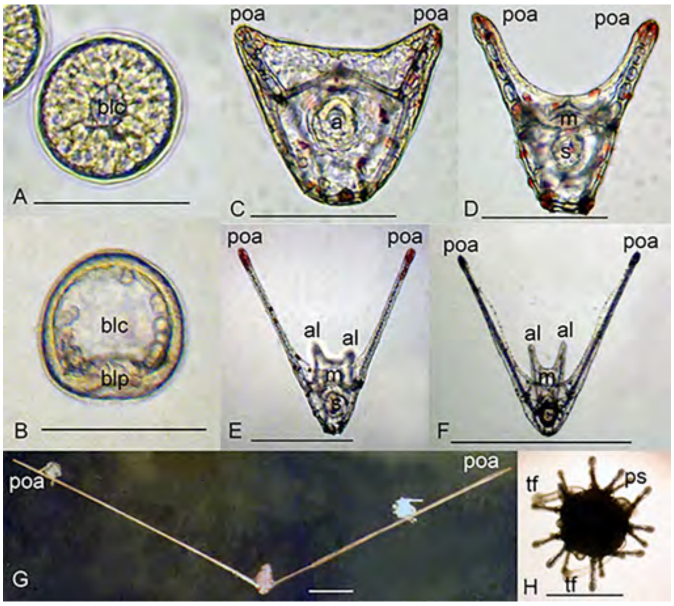

FIGURE 5. Larval development of *Diadema savignyi* (Audouin, 1829). (A) Early spherical blastula shortly before hatching. blc – small blastocoel with a diameter about one-third of the blastula. (B) Early gastrula, view from the ventral side, blc – blastocoel, blp – blastopore. (C) Late prism. a – anus, poa – postoral arms. (D) Early pluteus with one pair of arms. m – mouth, poa – postoral arms, s – stomach. (E) 3-day-old pluteus. al – anterolateral arms, m – mouth, poa – postoral arms, s – stomach. (F) 14-day-old pluteus, al – anterolateral arms, m – mouth, poa – postoral arms. (G) Dissecting microscope. Combined picture of common view of the pluteus. poa – postoral arms. For comparison, two late plutei of *Toxopneustes pileolus* are shown. (H) Juvenile sea urchin soon after metamorphosis. ps – primary spines, tf – tube feet. Scale bar: (A), (B), (C), (D) – 100 μm, (E) – 200 μm, (F), (G), (H) – 500 μm.

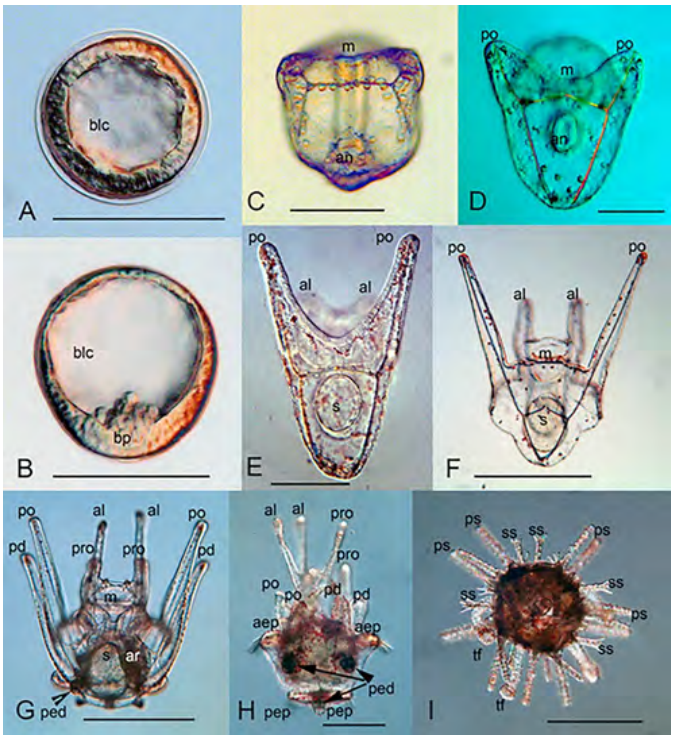

FIGURE 6. Larval development of *Mesocentrotus nudus* (A. Agassiz, 1864). (A) Early spherical blastula. bcl – blastocoel. (B) Early gastrula at the beginning of gastrulation. blc – blastocoel, bp – blastopore. (C) Late prism just after mouth opening formation. an – anus, m – mouth. (D) 4-day old pluteus with 2 postoral arms. an – anus, m – mouth, po – postoral arms. (E) 4-day old pluteus with 4 arms. al – anterolateral arms, po – postoral arms, s – stomach. (F) 9-day old pluteus with 4 arms. al – anterolateral arms, m – mouth, po – postoral arms, s – stomach. (G) 18-day old pluteus with 8 arms with adult sea urchin rudiments. al – anterolateral arms, ar – adult sea urchin rudiments, m – mouth, pd – posterodorsal arms, ped – pedicellaria, po – postoral arms, pro preoral arms, s – stomach. (H) 31-day old pluteus with eight arms, epaulettes, and three pedicellariae. aep – anterior epaulettes, al – anterolateral arms, pd – posterodorsal arms, ped – pedicellariae, pep – posterior epaulettes, pro – preoral arms. (I) Juvenile with tube feet and primary and secondary spines. ps – primary spines, ss – secondary spines, tf – tube feet. Scale bar: (A), (B), (C), (D) – 100μm, (E), (F) – 200 μm, (G), (H) – 300 μm, (I) – 500 μm.

savignyi had diameters of 63.8-94.9 μm with an average value of 79.24 ± 6.37 μm (n=149). Immediately after hatching, the blastulae were spherical and 100 μm in diameter and usually swam around the longitudinal axis in the upper layer of water (Figure 5(A)). After about 15–18 h. a.f., the spherical blastulae became slightly elongated. Shortly before gastrulation began, the wall of the blastula's body became thinner, the blastocoel became more spacious and two groups of mesenchymal cells that formed two primary triaxial spicules were visible (Figure 5(B)). The larvae became prisms during gastrulation. The blastopore, located on the vegetal pole of the larva, shifted to the ventral side of larvae. Prisms had a blastopore, which became the anus, and after the prism stage was completed, the mouth had appeared (Figure 5(C)).

Development of the *D. savignyi* pluteus consisted of several stages. The first stage, immediately after the prism, was the pluteus stage with one pair of arms (Figure 5(D)). At this stage, pluteus already had a complete larval skeletal basket and digestive tract with mouth, oesophagus, stomach, and intestine with anus. A few hours later, the second pair of arms visualized in the larva (Figure 5(E)). Approximately up to the 8th day of development, the larvae had hand growth processes, and the postoral arms grew much faster than the anterolateral ones (Figure 5(E)).

During the development, the appearance of the larva changed. In addition to a substantial elongation of postoral arms, changes occurred in the proportions of the larval body which became shorter and more oval. Anterolateral arms gradually became so short that they were difficult to see (Figure 5(G)). Nevertheless, the rods of anterolateral arms were retained in the latest larvae. The larva was then settled down and the metamorphosis completed. The young sea urchin immediately after metamorphosis had five tube feet and fifteen primary spines (Figure 5(H)).

At the end of larval culture, we had about 30-50 juveniles from 1% of the eggs from three females.

3.2 Larvae of the sea urchins fam. Strongylocentrotidae Gregory, 1900

3.2.1 Mesocentrotus nudus (A. Agassiz, 1864)

The eggs obtained from female *Mesocentrotus nudus* had a diameter of 98.0±7.8 µm. First larval stage of this sea urchin was spherical blastula (Figure 6(A)). Blastula left the fertilization envelope and began its larval life. Blastulas swam around the anteroposterior axis of the body. Gastrulation began at second day a.f. (Figure 6(B)). Gastrulas swam around the longitudinal axis. From the bottom of the blastocoel (at the posterior end of the larval body), primary mesenchymal cells originate. They produced first skeletal ossicles.

At three days a.f., larvae became a prism. The archenteron reached the ectoderm at the ventral side, and the mouth appeared in a late prism (Figure 6(C)). At the blastocoel, one can see the skeletogenic cells and primary spicules. Four-day old late prism had the first pair of larval arms – postoral ones. The archenteron came to contact with the ectoderm, and the mouth had formed (Figure 6(C, D)).

Young pluteus (4-5 days a.f.) had differentiated digestive tracts, larval skeletal baskets, and attained anterolateral arms (Figure 6(E)). Late four-armed pluteus had well-developed postoral and anterolateral arms (Figure 6(F)).

Full-developed pluteus of *Mesocentrotus nudus* had eight arms (Figure 6(G)) – two postoral, two anterolateral, two posterodorsal, and two preoral ones. At the left side of the larvae, the rudiments of the adult sea urchin had developed (Figure 6(G)). The rudiment of primary pedicellaria can be recognized at the posterior part of the larval body. This larva swam and fed on phytoplankton.

Larva attained upper and lower epaulettes and three pedicellaria through further development (Figure 6(H)). The ciliary band of the pluteus is the main organ for swimming and feeding. At the end of the larval life, the larvae of regular sea urchins attained epaulettes – short segments of the ciliary band, which served only for swimming. Pluteus before metamorphosis had well-developed epaulettes and three pedicellariae. One can see the resorption of the larval arms (Figure 6(H)).

Time \ *Species*	***Diadema setosum*** **(26-28°C)**	***Diadema savignyi*** **(26-28°C)**	***Mesocentrotus nudus*** **(21°C)**
0 hour	Zygote	Zygote	Zygote
6-7 hours	Blastula	Blastula	–
18-19 hours	gastrula	gastrula	–
2 days	2 armed pluteus	2 armed pluteus	gastrula
3 days	4 armed pluteus	4 armed pluteus	prism
4 days	4 armed pluteus	4 armed pluteus	2 armed pluteus
6 days	4 armed pluteus	4 armed pluteus	4 armed pluteus
9 days	4 armed pluteus	4 armed pluteus	6 armed pluteus
18 days	4 armed pluteus	4 armed pluteus	8 armed pluteus
30 days	4 armed pluteus	4 armed pluteus	Pluteus (epaulettes, pedicellaria)
31 days	4 armed pluteus	4 armed pluteus	Juvenile
44 days	Juvenile	4armed pluteus	–
47 days	–	Juvenile	–

TABLE 1. Time-developmental stage of *Diadema savignyi*, *D. setosum*, and *Mesocentrotus nudus* (T°C).

Stage \ **Species (egg size, µm)**	***D. setosum*** **(85)**	***D. savignyi*** **(80)**	***P. maculata*** **(97)**	***T. pileolus*** **(100)**	***T. gratilla*** **(84)**
Blastula	6.5 h	7-12 h	17 h	12 h	19 h
Prism	23 h	23-31 h	27 h	42 h	35-40 h
2-arm pluteus	44 h	48 h	42 h	60 h	50 h
4-arm pluteus	45 h	50 h	3 d	3 d	3 d
6-arm pluteus	–	–	11 d	12 d	12 d
8-arm pluteus	–	–	17 d	19-24 d	20-22 d
Metamorphosis	44 d	47-50 d	No	30-33 d	30-33 d

TABLE 2. Some dimensions and temporal parameters of embryonic and larval development of *Diadema setosum*, *D. savignyi*, *Pseudoboletia maculata*, *Toxopneustes pileolus*, and *Tripneustes gratilla* (personal observations, unpublished) (27 ± 1°C).

The metamorphosis included the reduction and collapse of the larval structures and appearance of the adult structures – test, primary and secondary spines, and tube feet (Figure 6(I)).

All larval development from the fertilization to metamorphosis took about 30-31 days at 21°C. At the end of cultivation, we had about a hundred juveniles from one larval culture.

The results of our investigation are summarized in Table 1. For comparison, we proposed the results of our preliminary studies on the dynamics of larval development in several common species of sea urchins from the Nha Trang Bay (Table 2).

Table 1 shows that the sea urchins Diadema have a longer larval stage compared to *Mesocentrotus nudus*. The temperature of development is an essential factor. We reared *M. nudus* at 21 ± 1 ° C. Considering that this sea urchin lives in the temperate waters of the Japanese and Yellow Seas, it requires a lower temperature compared to the conditions for keeping the culture of Diadema sea urchin larvae.

Table 2 shows the results of preliminary studies of maintaining cultures of larvae of common species of sea urchins from the Nha Trang Bay. It is seen that the popular mariculture object *Tripneustes gratilla* completed larval development and settled in 30-33 days. *Toxopneustes pileolus* also settled and underwent metamorphosis in 30-33 days. Another common species from the Nha Trang Bay, *Pseudoboletia maculata* may be the promising object of the mariculture. This sea urchin grew to an 8-armed pluteus in 17 days. Unfortunately, we were not able to bring the culture of the larvae of this sea urchin to metamorphosis.

4. DISCUSSION

McEdward and Miner (2001) provide a classification of the reproduction modes of all echinoderm species studied at the time. In a comprehensive review by Pearse and Cameron (1991), based on an analysis of the literature data, the general structure of echinopluteus of certain sea urchin orders is given. In all species considered in our investigation, the planktotrophic larva echinopluteus developed. Diadema had a modified larva, in which only two pairs of arms formed. The common structure of the larvae of two related species investigated was so similar that they were difficult to distinguish from each other. Sometimes they are called two-armed (Huggett, Catherine, Williamson, & Steinberg, 2005), since in the latest stages of their development in the late Diadema plutei, only a pair of postoral arms grew out of the two pairs of larval arms. The second pair of arms – anterolateral ones noticeably growing slower, although it did not completely disappear until the end of larval development. The skeletal rods of the anterolateral arms were preserved until the latest larval stages, so the Diadema plutei remained four-armed until metamorphosis. Larvae of *D. savignyi* and *D. setosum* differed from D. antillarum (Eckert, 1998). Late pluteus of D. antillarum had thicker arms and therefore can be easily distinguished from the pluteus of *D. setosum* and *D. savignyi*.

Some similarity in common characters of adult urchins, i.e., black colour, size of the test, length of spines (3-4 cm in *Mesocentrotus nudus*, about 30-40 cm in *Diadema setosum* and *D. savignyi*) bears some convergence. The ontogenesis and larval structure differed significantly.

Comparing larval morphology of *Mesocentrotus nudus* and *Diadema setosum* and *D. savignyi* shows weak resemblance. In all mentioned species, a blastula was the first larval stage. It dissolved the fertilization membrane and began its pelagic life. Blastula of Diadema had a thick wall and relatively small blastocoel. In *M. nudus*, blastula had relatively thin blastoderm.

The larvae of *D. setosum* and *D. savignyi* are practically indistinguishable in size and colour. Some differences in the structure of the larvae are visible only at the latest stages of development. The late pluteus of each species had clear and specific features. Plutei of Diadema have long arms (in *Diadema setosum* – about 2300 μm, in *Diadema savignyi* – about 5500 μm) whereas the length of the arms of *Mesocentrotus nudus* did not reach 1000 μm.

Pedicellaria are formed in some late plutei of both species of Diadema, and this pedicellariae is species-specific (Coppard & Campbell, 2006; Rahman et al., 2015; Dautov, personal observation, unpublished). All late plutei *Mesocentrotus nudus* have three pedicellariae.

Pedicellaria in regular sea urchins are an obligatory attribute of the late stages of the pluteus. They are situated on the right side of the pluteus body and somehow participate in the process of settlement and temporary attachment to the substratum. The absence of pedicellaria in the late pluteus can speak of the abnormal development of the larva (Burke, 1980). In larvae of Diadema, probably, these formations are optional.

The differences in the length of the postoral arms of the plutei of *Diadema savignyi* and *D. setosum* cannot be the result of differences in the growing conditions, since larvae of both species were kept in the same conditions.

The difference in the developmental duration of Diadema sea urchins between our cultures and the data obtained by Rahman et al. (2014) on *D. setosum* in Malaysia and Eckert (1998) on D. antillarum, can indicate a difference in the genetics level of these species and the conditions of the cultivation and feeding of larvae.

Perhaps, it will be possible to modify the scheme of cultivation of larvae, which will affect the time of larval development. This will be the content of further experiments with these interesting marine animals.

Until early 1990, Strongylocentrotus intermedius and *Mesocentrotus nudus* abounded off the coast of Primorye region. With the beginning of 2000, the situation changed. Natural seafood sharply went up in price on the world market, which led, in particular, to an increase in interest in the oriental way of life and nutrition. Demand and prices for sea urchins and their caviar increased. Now when the S. intermedius has been caught almost entirely and become noticeably rare, interest to *Mesocentrotus nudus* as a fishing target has grown significantly. *M. nudus* inhabits the same places that S. intermedius. Larval morphology of the *M. nudus* differs from the specific morphology of the larvae of genus Strongylocentrotus members. Young S. intermedius pluteus have an outstretched posterior tip of the body (Naidenko, 1983). In *Mesocentrotus nudus*, the posterior tip of the body is rounded. There are differences between late plutei. Late pluteus Strongylocentrotus intermedius has a pointed posterior end of the body and greenish body colour. In the *Mesocentrotus nudus*, late pluteus has a rounded posterior end of the body and a dark reddish colour.

We can compare the temporal characteristics of the larval development of the species studied. In all cases, the results obtained can be useful for developing schemes for obtaining juvenile stages that can be used as a seed.

The world's most edible species of sea urchins are: Centrostephanus rodgersii, Echinometra sp., Evechinus chloroticus, Heliocidaris erythrogramma, Loxechinus albus, Lytechinus variegatus, Paracentrotus lividus, Psammechinus miliaris, Salmacis sphaeroides, Strongylocentrotus droebachiensis, Strongylocentrotus franciscanus, Strongylocentrotus intermedius, Strongylocentrotus (Mesocentrotus) nudus (the most popular in Japan ~44%), Strongylocentrotus purpuratus, and *Tripneustes gratilla*. The last species – *Tripneustes gratilla* – lives in Viet Nam and can be used as a potential object for marine farming. This species is now harvested from natural populations, and there is a fear of overfishing. In the near future, one will certainly need to restore its population.

Diadema setosum and *D. savignyi* are not in the list mentioned previously. Nonetheless, in Malaysia, *D. setosum* is cultivated (Rahman et al., 2015) and is in demand among customers of seafood restaurants.

5. CONCLUSIONS

For sea urchins proposed by us, embryonic and larval development is described, with a detailed description of all stages.

Due to its specific structure, the larvae of the genus Diadema are sometimes called two-armed. The development time to metamorphosis in the Diadema can vary, which can be explained by the characteristics of laboratory cultures (especially at high temperature) and the properties of local populations. The whole development takes about 45-46 days at 26-27°C.

Mesocentrotus nudus have a typical 8-handed pluteus, which differs slightly from the morphology of larvae of sea urchin genus Strongylocentrotus. Development of the *M. nudus* takes about 30 days at 21°C. Cultivation at moderate temperatures reduces the cost of preparing seawater.

Despite of the small percentage of juvenile specimens (0.001% or lower), the proposed cultivation scheme may well be used to obtain seed that can be further grown in suitable controlled water areas.

One can compare the common structure of the larvae from obtained culture with the figures from the article. This gives hope that research can be used to improve people's lives.

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Lessons learnt from implementing training on Ecosystems Resilience in a Changing Climate for sectoral development in South and Southeast Asia

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HIGHLIGHTS

- A unique opportunity to initiate mainstreaming ecosystem resilience into the government sector as well as integrating the idea amongst the research community.
- Practitioners and the research community with no prior experience could be effectively trained in four days to initiate the integration of ecosystem resilience in their respective sectoral development plans.
- The success of the training was strengthened by collaborative interaction among newly trained practitioners, facilitators and members of the ecosystem management fraternity.
- Opened new avenues of collaboration for the stakeholders as ecosystem resilience in changing climate is to be carried out in an integrated manner by all the stakeholders rather than in silos.

ABSTRACT

Climate change has a considerable impact on weather patterns worldwide. Therefore, planning and decision-making processes based on information on farmers' traditional and indigenous knowledge may no longer be accurate and useful. Respective national and local authorities have not been giving due attention to address this issue, and farmers and their dependents have been facing difficulties to sustain their livelihoods in the face of climate change. To ensure enhanced agro-ecosystem services and functions as part of policy interventions at national and sub-national levels, a four-day training course was developed and conducted for practitioners and policymakers on "Agro-ecosystem Resilience in a Changing Climate". The training course created a pool of master trainers from government, academia, and non-governmental organizations (NGOs) in understanding agro-ecosystems, their functions and threats posed to them by weather and climate change in order to build resilience. The target countries were Nepal, Thailand and Sri Lanka. An evaluation questionnaire was developed (Likert scale and short answer types) to analyze participants' feedback and lessons learnt from the training courses. The results were mostly constructive and, in most cases, positive. The attendees gained sufficient knowledge to implement the adaptive measures as well as it opened new avenues of collaboration for the stakeholders.

1. INTRODUCTION

Addressing climate change impacts, developing an adaptation strategy and an action plan are challenging and complex tasks. Weather pattern worldwide has been impacted by the effects of climate change (Singh & Singh, 2012), which is leading to limitations in planning and decision-making based on information on traditional and indigenous knowledge of farmers. It is also well known that agro-ecosystems are fragile to environmental shocks. Climate change affects agro-ecosystem due to changes in regular weather and climate patterns, creating compound effects through droughts, floods, heat waves and other hydro-meteorological events.

Climate has a significant environmental influence on ecosystems. Climate change has been making measurable impacts on agriculture in a wide range of economies, crops and farming systems affecting crop productivity, food security and livelihood security (Weerasinghe, Arambepola, Rathnayake, & Nawaratne, 2014). Climate change not only affects ecosystems and species directly, but it also interacts with other human stressors such as development. Although some stressors cause only minor impacts when acting alone, their cumulative impacts may lead to dramatic ecological changes. Therefore, awareness creating through training and capacity building programmes would help study problems and addressing policy issues while also mainstreaming ecosystem resilience through effective use of climate and weather information. This would also allow strengthening interactions among the scientist and policymakers to improve policy-decision for ecosystems resilience (Weerasinghe et al., 2014).

Given the above, practitioners and policymakers require 1) an understanding of weather and climate and slow and rapid onset of disasters; 2) orientation towards disaster preparedness based on climate outlook. These are essential to mainstream the application of climate information and utilize adaptive technological solutions as remedial measures to improve agro-ecosystems and secure agriculture livelihoods. The purpose of the manuscript is to discuss the lessons learned and the challenges faced in carrying out the multi-country training on "Ecosystems Resilience in a Changing Climate".

2. METHODOLOGY

The four-day training course was conceptualized to create awareness and build the capacity of relevant government officials and practitioners in Nepal, Sri Lanka, Thailand and Viet Nam for effective utilization of weather and climate information, and adaptive technological solutions in order to enhance agro-ecosystem resilience. As the majority of the agro-ecological systems in the four countries were rural, thus the main thrust in building resilience of rural social-ecological systems was to ensure the sustainability of livelihoods, which underwrites food security of rural communities.

The course adopted a broader paradigm where the resilience of agro-ecological systems was entwined with concepts of sustainable livelihoods and food security. It embraced a view of agro-ecosystems inclusive of land farming systems & livestock, aquaculture, fishery and forestry practices (FAO, 2015) which strengthen rural livelihoods, their sustainability and diversity, and contribute to food security. It endeavoured to provide the participant with the know-how on analyzing factors that influence sustainability and resilience of agro-ecosystems and develop interventions to sustain the productivity of these systems in the face of climate change by integrating weather and climate information. The course was designed as a Training of Trainers (ToT) course to enable customization by national-level organizations to train sub-national/provincial level officials to support long-term sustainability towards mainstreaming agro-ecosystem resilience.

One unique aspect of the four training modules developed for the course was the incorporation of experiences gathered from a development program run by the Asian Disaster Preparedness Center (ADPC). The program was conducted from 2012-2015 in the Nilwala river basin of Sri Lanka and Mekong river basin of Viet Nam with funding from Australian Aid. The focus of the program was on mainstreaming the application of climate information to enhance agro-ecosystem services and functions. The program provided the know-how on analyzing factors that influence sustainability and resilience of agro-ecosystems and develop interventions to sustain the productivity of these systems in the face of climate change by integrating weather and climate information. The field research activities of the program provided opportunities to work with farmers in real situations by rallying all the stakeholder organizations (central government, local agriculture, irrigation, meteorological authorities, University of Ruhuna, Sri Lanka and Cantho University, Viet Nam) on to a common platform, which was used to develop course material and trainer guidelines. The training course modules on "Agro-ecosystem Resilience in a Changing Climate", developed from this project, modified through a curriculum review process to suit national-level participants for the current training course. The four modules were finalized through a consultative process and underwent extensive review from external experts.

- Module 1: Relevance of Disaster and Climate Risk Management for Sustainability of Social-Ecological Systems: This module introduced basic terminology of disaster risk management, climate change science and impacts of climate-related disasters in the agriculture sector. It also described the agro-ecosystem as a social-ecological system, and ecosystem-based approaches (EBA) are required to build their resilience.
- Module 2: Generation and Application of Weather and Climate-Related Information: This Module provided a discussion of climate information generation, their dissemination and potential applications to build the resilience of agro-ecosystems.
- Module 3: Planning for Vulnerability Reduction and Resilience Building of Agro-ecosystems: This Module provided background information for project formulation using accepted approaches and tools including Theory of Change, Log frame Analysis, Multicriteria analysis, and others. This formed the basis for

the scenario-based group work.

» Module 4: Synthesis of Learnings through a Scenario-Based Exercise: During this module, participants applied their learnings from previous modules to develop a climate resilience strategy based on a given scenario suitable for their respective country.

The training course was designed, and materials prepared, taking into consideration the following:

1. Limited focus of training on agricultural techniques, which often neglects the relevant principles of the environment such as recycling, enhancement of natural processes, and the synergy between various elements;
2. Limited availability of good, experienced trainers in terms of content, training methods, approaches and skills;
3. Poor documentation of training experiences;
4. Limited availability of relevant training materials;
5. Lack of participatory training and extension approach combining environmental education and agriculture;
6. Limited exchange of training information between environment and agriculture trainers.

The first three training courses were conducted in Ho Chi Minh City, Viet Nam from 29 May to 01 June 2017; Colombo, Sri Lanka from 12-15 June 2017 and Phetchaburi, Thailand from 27-30 March 2018. the fourth training course was conducted at Kathmandu, Nepal from 5-8 June 2018 and the final course was conducted in Chilaw, Sri Lanka from 27-30 May 2019. The training course constituted lecture-based classes, case study screening on building the resilience of an agro-ecosystem, group work on weather and climate information dissemination, theory of change, logical frame analysis, multi-criteria analysis, cost-benefit analysis and country-specific scenario-based exercises. Through this course, the participants had greater opportunities to interact with facilitators and exchange their experiences, views and ideas throughout the course and during their presentations.

Towards the end of each training course, an evaluation questionnaire was provided to each of the participants. The anonymous questionnaire enabled

Evaluation topic	*Question Number*	*Question*	*Response Type*
Overall Course Evaluation	Q1	How much did you learn from the course?	Likert-type scale
	Q2	What are the other subjects that should be added to the course?	Short answer
	Q3	What are the subjects that should be removed from the course?	Short answer
Time Allocation	Q4	Theoretical Content	Likert-type scale
		Group Activities	Likert-type scale
		Group Discussion	Likert-type scale
		Experience Sharing	Likert-type scale
		Game Activities	Likert-type scale
Course Organisation (Logistics)	Q5	Effectiveness	Likert-type scale
		Helpfulness	Likert-type scale
		Overall Coordination	Likert-type scale
Course Delivery Evaluation (Day wise Topic)	Q6	Overall Content	Likert-type scale
		Method of Delivery	Likert-type scale
		Workbook Content	Likert-type scale
Target Audience	Q7	Have the organizers correctly identified the target audience? Or any other gap in the competency of the audience?	Short answer
Knowledge Transfer and Relevance	Q8	How do you apply the knowledge you have gained from the course?	Short answer
	Q9	What are the suggestions to implement new concepts learnt from the workshops at your institutions?	Short answer
	Q10	How do you plan to clarify any doubts on the content, or about the implementation? Have you built contacts with facilitators?	Short answer
	Q11	How do you plan to approach the heads of your organization in applying the content learnt in the course?	Short answer
	Q12	Do you think the content delivered in the workshop is relevant/ irrelevant to your organization? List pros and cons.?	Short answer
	Q13	Other comments and suggestions?	Short answer

TABLE 1. Summary of questions on the written training evaluation.

to understand the expectations of the participants and also enabled to evaluate the knowledge gained during the training (Verhougstraete, Brothers, Litaker, Blackwood, & Noble, 2015), overall training experience, training material, training technique/environment and organization. The evaluation questionnaire comprised of several Likert-type (Chang, 1994; Croasmun & Lee, 2011; Boone & Boone, 2012; Sullivan & Artino Jr, 2013) scaled questions (Verhougstraete et al., 2015) as well as open-ended questions aimed at supporting the Likert-type scaled questions. Responses for Likert-type scaled questions were evaluated using percent agreement. A thematic classification of the open-ended questions was also carried out. The evaluation aimed to obtain participants feedback on the following: 1) overall training experience; 2) time allocation on training components; 3) course delivery including training material and method and 4) knowledge transfer and relevance. The questionnaire provided is summarized in Table 1, including the type of answer, i.e. Likert-type scale or short answer. The evaluation was carried out with input from capacity development experts within the organization.

3. RESULTS AND DISCUSSION

Participants' responses to the evaluation questionnaire were mostly constructive and in most of the cases positive. The following section discusses the feedback from participants (questionnaire responses) and analyses the lessons learnt from the training courses. The data analysis has been carried out for only the workshops held in Sri Lanka, Thailand and Nepal as the Viet Nam training course was a pilot run of the developed training modules and responses to the questionnaire are not comparable with the other three countries. In fact, some of the questions of the questionnaire were modified or added after the Viet Nam pilot training, and thus the response is not comparable.

3.1 Overall evaluation of the course

As shown in Figure 1, participants from Sri Lanka and Thailand expressed more positive views in their evaluations than participants in the Nepal training course. In addition to the analysis results below, the responses to the short answer questions depicted that the participants expected further knowledge on means of communication of ecosystem resilience practices to the farming community. They also expected knowledge on flood forecasting, examples of cost-benefit analysis carried out in various projects as well as country-specific examples on change management. It was also informed that a module on proposal development on ecosystem resilience would have been beneficial. One of the reasons for low satisfaction of participants in the Nepal training is lack of information on climate change impacts and resilience in Nepal (Gurung & Bhandari, 2009) and more focus on theoretical concepts than practical examples from Nepal or countries with similar ecosystems. It was also reported through the short questions that although the course was on ecosystem resilience in changing climate (Bhatta et al., 2015; Isabelle & Darling, 2010), considerable time was devoted to basic concepts and disaster.

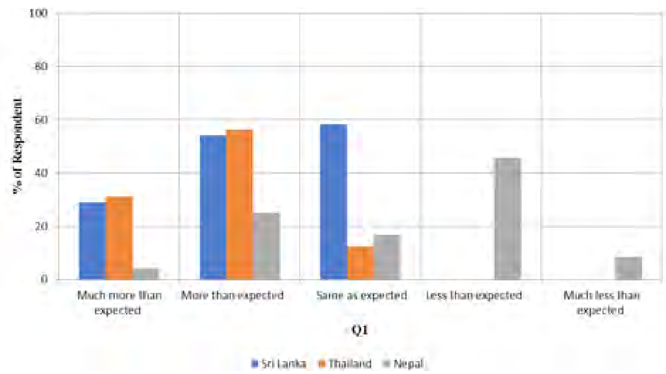

FIGURE 1. Country-wise evaluation of the course.

3.2 Time allocation

The time allocation on various components of the course, e.g. theoretical content, activities, the scope of interaction with the facilitator and opportunity to share amongst participants were evaluated through Q4. The analysis results are given in Figure 2. The analysis was carried out by compiling responses of all participants from three countries. It was observed that most of the participants in all three countries gave an average scoring to the time allocation for each of the training components. It was observed that experience sharing was just adequate and could have been allocated more time.

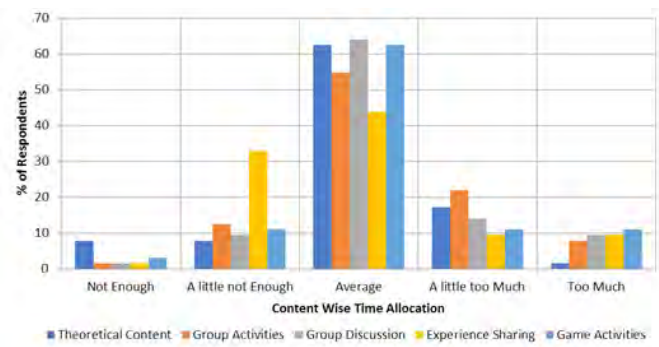

FIGURE 2. Response on time allocation for various components of course from all the three countries.

3.3 Course organization

The course organization, including effectiveness and overall coordination, received a considerable satisfaction level from more than 40% of the participants. In comparison, more than 40% were highly satisfied with the helpfulness of the course organizers. The majority believed that the logistics were adequate, and the overall coordination was satisfactory.

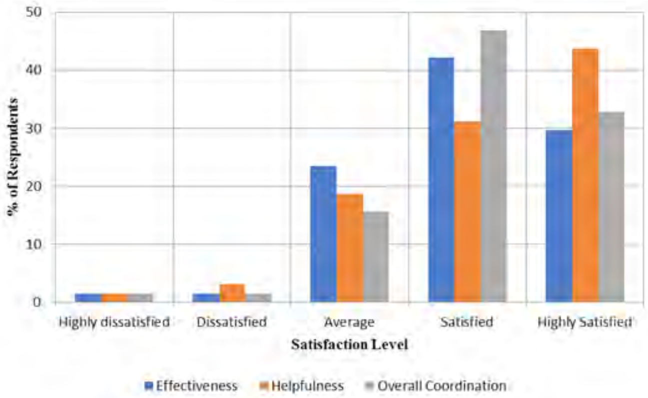

FIGURE 3. Satisfaction level of participants on course organization, including logistics from three countries.

3.4 Course delivery

The evaluation also considered course delivery mechanism which tried to understand the participants view on the overall technical components of the course which constituted of four modules delivered over four days, as well as facilitators' competency. The responses of the participants' country-wise are analyzed below. The Likert scale for content was classified as 1 = not useful, 2 = not so useful, 3 = average, 4 = useful, 5 = very useful while the Likert scale for Method of Delivery and Workbook Content were classified as 1 = strongly need improvement, 2 = need improvement, 3 = neutral, 4 = good, 5 = very good. Figure 4, 5 and 6 shows that majority of the participants of the training course in three countries found the content useful or very useful and found the method of delivery and Workbook content good or very good.

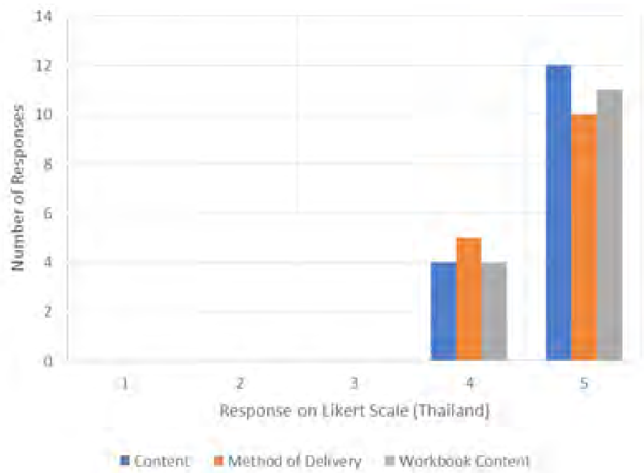

FIGURE 4. Course delivery evaluation of Thailand Training Course.

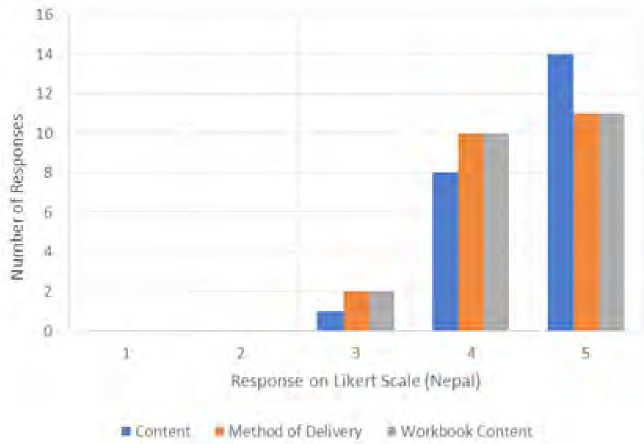

FIGURE 5. Course delivery evaluation of Nepal Training Course

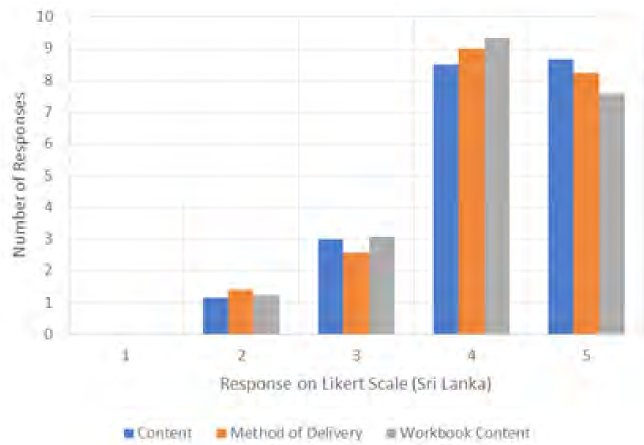

FIGURE 6. Course delivery evaluation of Sri Lanka Training Course.

Based on the analysis for individual countries, the average responses of participants (Likert, 1932) were also analyzed for questions 1, 4.1–4.5, 5.1–5.3 and 6.1–6.3 as shown below. The average response is calculated using the following formula:

$$Average\ response = \frac{\sum_{i=1}^{5} L_1 f_1}{n}$$

Where L_1 = Value of the Likert scale response (from 1 to 5),

f_1 = Number of the responses for the respective value of the Likert Scale and

n = Number of total responses

It should be noted that question 4 refers to time allocations, 5 refers to the ADPC logistics support, and 6 refers to the course delivery evaluations. Figure 7 indicates that the average response in Likert type scale question is average to good which indicates the overall success of the course.

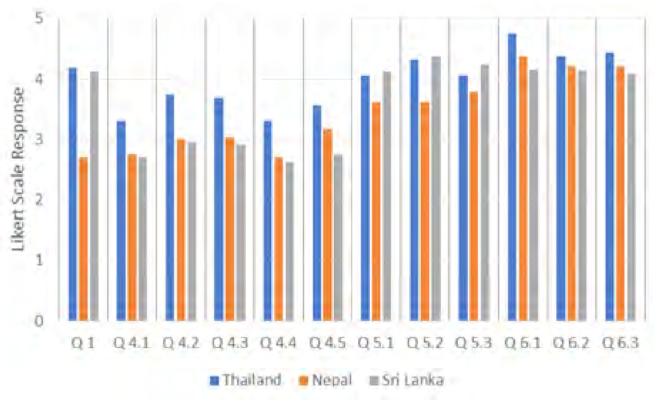

FIGURE 7. Average responses of participants from three countries to the Likert type scale questions.

3.5 Target audience, knowledge transfer mechanism and relevance

Several short answer questions were also part of the evaluation questionnaire, and the response of the participants indicated that facilitators were competent enough to deliver the course and most of the participants indicated they were satisfied with the facilitators. Regarding the target audience, it was indicated that although there was a mix of participants from sectors, participation from some important stakeholders were missing, such as wildlife, agro-researchers and coastal management authorities. Regarding the transfer of knowledge gained through the training course most of the participants indicated that they foresee transfer of knowledge by the development of proposals in the subject area with relevant stakeholders, organizing training courses within their respective organization for knowledge dissemination and ground-level implementation. Some of the participants indicated that they would discuss with relevant authorities of the organization for integration into programs of the department. Regarding the relevance of the course to the organizations represented, the majority of participants indicated that the training course was highly relatable to their organizations' work profile.

3.6 Future training course

The training course evaluation questionnaire and personal feedback from participants taught us that the biggest impediments to the universal adoption of ecosystem resilience would be variability across users. While there is no immediate solution for this, but the key to success would be mainstreaming ecosystem resilience into the workflow of major sectors like agriculture, water resources, coastal systems and integrated approach amongst the stakeholders.

Following participants' feedback, we suggest implementing the points below in future training courses:

1. Reduce theoretical lecture time;
2. Provide more practical-oriented lectures including an introduction to decision-making software tools;
3. Increase group activities and critical thinking assignments;
4. Increase time for cost-benefit and multi-criteria analysis;
5. Enhance time management; and
6. Provide orientation on ecosystem resilience-related proposal writing for better mainstreaming in sectoral development plans.

4. CONCLUSION

The four training courses gave a unique opportunity to initiate mainstreaming ecosystem resilience into various sectors of the government as well as integrating the idea among the research community. The key findings of the four training activities demonstrated that 1) practitioners and research members of the community with no prior experience could be effectively trained in four days to initiate integration of ecosystem resilience in their respective sectoral development plans; 2) The average set objectives of the training has been achieved in all the training courses and majority of participants have expressed satisfaction on the course content, delivery mechanism, time allocation and overall learning from the course; 3) some deviation can be observed in the training course organized in Nepal where the training course hasn't been able to meet the expectations of many of the participants which may be due to time management and the facilitators may not have correctly identified the audience before sharing knowledge; 4) it was also noticed that some participants have stated explicitly that in one or two instances facilitators contradicted on some information amongst themselves thus requiring a more co-ordinated approach to the training in future and 5) suggestions have been provided to share pre-course material to reduce time on theoretical aspects and devote more time in practice, seminar and group interactions. It was also found that the most successful workshop was held in Sri Lanka, and this may be attributed to better coordination, choosing the appropriate trainee organization and a well-defined mix of stakeholders.

During future workshops, we suggest a daily summary and group discussion to reiterate important concepts applied daily and to elicit further inquiries. The discussion offers participants the option to reflect, enquire and receive feedback from the facilitators in an informal setting. This also helps foster peer relationships and improve peer support, leading to more significant knowledge gain.

The success of these training workshops was strengthened by collaborative interactions amongst newly trained practitioners, facilitators and members of the ecosystem management fraternity. The training course also opened up new avenues of collaboration for the stakeholders as ecosystem resilience in changing climate is to be carried out in an integrated manner by all the stakeholders rather than in silos.

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Atmospheric chemistry research in Monsoon Asia and Oceania: Current status and future prospects

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ABSTRACT

We aimed to foster the community of atmospheric scientists in the Monsoon Asia and Oceania (MANGO) region to enhance communication among scientists in different countries and strengthen collaborations with the international community, with emphasis on air quality in Asia as it impacts human health and climate change. For this purpose, we have established a regional group, the International Global Atmospheric Chemistry–MANGO (IGAC–MANGO), under the IGAC project sponsored by Future Earth and the international Commission on Atmospheric Chemistry and Global Pollution. Through a series of committee meetings, scientific workshops, and training courses for students and early-career scientists, we analysed scientific activities in each country and identified research priorities in the MANGO region, significantly contributing to enhancing the capability and capacity of air quality research as well as fostering the next generation of scientists in the MANGO region.

HIGHLIGHTS

» A grassroots-level network was built for scientists in Monsoon Asia and Oceania.

» Priority themes in atmospheric chemistry in Monsoon Asia were identified.

» Air quality and human health research using low-cost sensors were established.

1. INTRODUCTION

The Monsoon Asia region is home to many countries undergoing rapid industrialization in response to the demand for economic growth. As a large portion of this region is located in a domain with copious amounts of water vapour and solar radiation, emissions associated with rapid urbanization lead to severe air pollution via complex atmospheric chemistry, causing critical environmental problems that are common among neighbouring nations. In addition, the region is characterized by complex meteorology, with regular pollution transport from seasonal and perennial anthropogenic sources (e.g., urban emissions).

In recognition of the common scientific challenges associated with critical environmental issues, and considering emerging atmospheric chemistry activities in South and Southeast Asia (A Sustainable Atmosphere for the Kathmandu Valley (SusKat); Atmospheric Composition and the Asian Monsoon (ACAM)), IGAC explored the feasibility of forming a Southeast Asia Working Group at its steering committee meeting in 2012 with a one-year scoping period. The idea was further discussed and evolved to become an overarching Asia Working Group, and the formal proposal was presented at the 2013 IGAC SSC meeting. Then, a core-preparatory committee was formed from Northeast, Southeast, and South Asia, and the possible structure was discussed and approved in the IGAC SSC meeting in 2014. To begin with, two workshops were held with the support from the NIES International Coordination Fund for two years (2014–2015) and the group officially started with the initial 17 members and three co-chairs from Northeast, Southeast, and South Asia. This group was named as the Monsoon Asia and Oceania Networking Group (MANGO) (Tanimoto, Kim Oanh, & Lawrence, 2015a; Tanimoto, Kim Oanh, & Lawrence, 2015b). Since 2017, the activities of MANGO have been boosted by the APN CAPaBLE fund "CBA2017-02MY-Tanimoto: Fostering of the next generation of scientists for better understanding of air quality in the Monsoon Asia and Oceania region".

As the group was inexperienced, there was a need to strengthen the working relationships among the members. Furthermore, although Monsoon Asia is a "frontier" for atmospheric chemistry research, the scientific studies by the scientists in the region as well as by the international community are limited. Hence, it was necessary to engage different countries from the Monsoon Asia region by holding meetings and capacity-building workshops to foster the community and enhance communication among scientists as well as between scientists and policymakers, and to establish close collaborations with the international community.

For this purpose, IGAC–MANGO aimed to form a cohesive network of atmospheric scientists in the Asian monsoon region, facilitate collaboration between Asian and international scientists, and foster the next generation of scientists in this region.

2. METHODOLOGY

To establish a robust structure using top-down and bottom-up approaches, the capacity development activities were organized by IGAC-MANGO and were three-fold: (1) committee meetings for country members; (2) scientific workshops for scientists including students and early- and mid-career scientists; and (3) training courses for students and early-career scientists that included hands-on sessions and science-policy panel discussions.

2.1 MANGO committee meetings

The IGAC–MANGO committee consists of members from South Asia, Southeast Asia, Northeast Asia, and Oceania. The committee meetings were held to discuss priority themes and scientific activities to be strongly pushed forward in the MANGO region. The committee also discussed how to enhance communication between scientists in Monsoon Asia, promote collaborations of the Asian community with the international community, and explore opportunities for funding and infrastructure that were needed to foster scientific research, capacity building, and regional collaborations.

2.2 MANGO science workshops

By bringing together scientists on atmospheric chemistry and environmental changes from East, South and Southeast Asia, science workshops were held to enhance knowledge exchange and foster new knowledge for scientists, policymakers and other relevant stakeholders in Asia. These workshops were also planned to help characterize regional similarities and differences in Asia and to identify and assess air pollution and global change issues at local, national, and regional levels. Recently, a virtual knowledge-sharing workshop was conducted to assess the regional and local impacts of COVID-19 on air quality (Tanimoto et al., 2020). These information exchanges provided a crucial opportunity to build on existing and establish new networks and relationships among scientists and policymakers throughout the region. Furthermore, these workshops enabled us to identify priority areas for collaborative research among atmospheric scientists in the MANGO region.

2.3 MANGO training courses

Training courses were held for students and early career scientists (ECS) from developing countries in Asia to provide hands-on practises with emission inventory, satellite data, and air quality modelling as well as basic air pollution instruments. The course also included science-policy engagement to help bridge science and policy for the ECS. In addition, experts were engaged to participate in the workshop through a panel discussion to learn the relationship-building process.

3. RESULTS AND DISCUSSION

First, we recognized that the Monsoon Asia region is facing severe environmental issues, including air pollution and climate change, and that the role of atmospheric scientists in understanding scientific principles and providing scientific support to policymakers is of utmost importance. Therefore, we identified three critical factors exemplified as a three-legged stool for the development and growth of atmospheric chemistry research in the MANGO region (Figure 1). This approach entails science themes, human resources, and infrastructure that must each be firmly rooted and balanced in the community, and connected to the IGAC's focal areas.

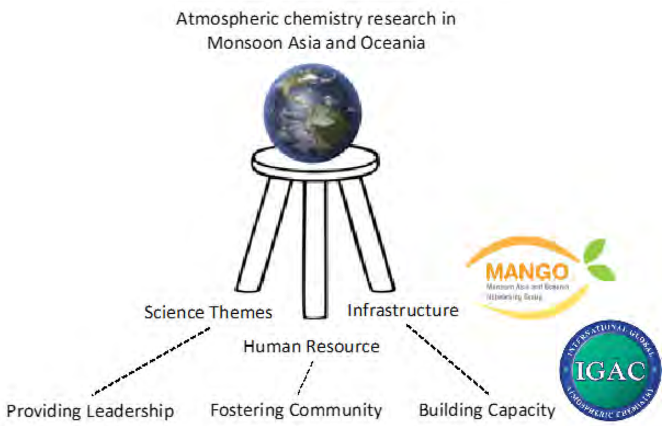

FIGURE 1. Three-legged stool approach to atmospheric chemistry research in MANGO requires science themes, human resource, and infrastructure that must each be strongly rooted and balanced in the community, and connected to the IGAC's focal areas.

3.1 Priority and emerging scientific themes

In recent years, Monsoon Asia has become a "frontier" for atmospheric chemistry research at the international level. One of the earlier projects, Atmospheric Brown Clouds (ABC) in the 2000s (Ramanathan & Crutzen, 2003), alerted the world that South Asia is a global air pollution hotspot, based on extensive observations carried out during Indian Ocean Experiments (INDOEX). Afterwards, the SusKat project was initiated jointly by the Institute for Advanced Sustainability Studies (IASS) and the International Centre for Integrated Mountain Development (ICIMOD) in 2012). The study focussed on the Kathmandu Valley in Nepal and addressed the relative roles of various pollution sources. In 2013, the ACAM project was initiated by the joint efforts of the IGAC and SPARC (Stratosphere–troposphere Processes And their Role in Climate) projects with a particular focus on four scientific themes relevant to air pollution and climate change in Asia: emissions and air quality in the Asian monsoon region; aerosols, clouds, and their interactions with the Asian monsoon; the impact of monsoon convection on chemistry; and the UTLS (the upper troposphere and the lower stratosphere) response to the Asian monsoon (Pan et al., 2014; Schlager, Chin, Latif, & Ahamad, 2019). Other studies include StratoClim (Stratospheric and upper tropospheric processes for better climate predictions) flight campaigns made over Nepal, India, and Bangladesh ("Balloon campaigns taking place simultaneously with the aircraft campaign," 2017), the AERONET (AErosol RObotic NETwork) project (AERONET), and SPARTAN (Surface Particulate Matter Network) project (SPARTAN: A Global Particulate Matter Network).

As such, research activities on atmospheric chemistry and air pollution need a significant boost in many Asian countries. Airborne pollutants are a major environmental health risk across the MANGO region, where they are responsible for the premature deaths of a few million people annually. Also, many Asian countries need to improve their understanding of changes in regional climate, which is vital for decision-making processes regarding adaptation, mitigation and sustainable development.

We identified the following priority themes associated with emerging scientific and environmental issues that are common across MANGO countries:

» Air quality and health, including indoor air quality issues;
» Biomass burning and anthropogenic emissions, and trans-boundary haze pollution;
» Changes in atmospheric composition and interplay with Asian monsoons; and
» Air pollution and climate change.

3.2 Human resource capacity

Despite the importance of tackling the above-mentioned scientific themes relevant to air quality, the capacity of human resources and infrastructure have yet to be improved. In the MANGO region, the number of atmospheric scientists was insufficient, and the scientists were not well connected to the international scientific community. There was large asymmetry among the countries in the capacity to conduct scientific research. Hence, coordination across Asian nations was developed, especially with a focus on countries that are not big enough to have a national community, resulting in a cohesive network of atmospheric scientists in the Asian monsoon region.

Currently, the committee is represented by 17 different countries/regions: Australia, Bangladesh, China, Hong Kong, India, Indonesia, Japan, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan ROC, Thailand, and Vietnam (Naja, Yu, Salam, & Tanimoto, 2020). The committee continued its efforts to engage new members from currently under-represented countries, such as Bhutan, Maldives, Cambodia, Brunei, and South Korea.

In addition to enhancing the diversity of the current MANGO membership by including under-represented countries, we strived to promote the growth of the next generation of scientists in this region. One good measure was the participation of ECS in the 2018 joint 14th iCACGP Quadrennial Symposium and 15th IGAC Science Conference (iCACGP-IGAC 2018) (Tanimoto et al., 2018) held in Takamatsu, Japan. In this conference, which was held in Asia for the first time since 2012, 196 ECS from 17 APN member countries/regions participated. These countries/regions included Australia, Bangladesh, China, Hong Kong, India, Japan, Korea, Malaysia, Myanmar, Pakistan, Philippines, Russia, Singapore, Taiwan ROC, Thailand, the USA, and Vietnam. Notably, there were a total of 321 participants, inclusive of non-ECS, from 19 APN countries with Indonesia and Sri Lanka added to the above-listed countries. A large proportion of ECS came from Japan (31%) as Japan was the host country, followed by China (22%), USA (17%), South Korea (8%), India (5%), Australia (3%), Hong Kong (3%), and Bangladesh (3%). Smaller numbers of participants came from other countries (Figure 2). All the ECS participated in the face-to-face sessions and breakout discussions of atmospheric chemistry as they pertain to human activities, ecosystems, climate/weather, fundamental understanding, and future challenges (Ishino et al., 2018; Willis et al., 2018).

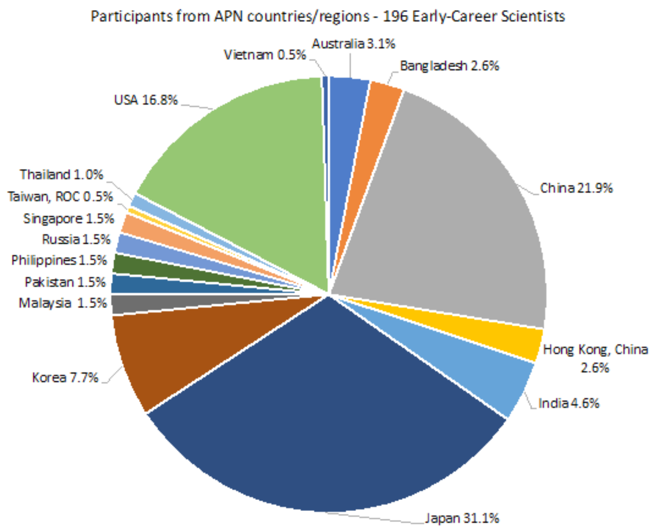

FIGURE 2. iCACGP-IGAC 2018 participants of early-career scientists from APN countries/regions. The definition of ECS is a current postgraduate student and a junior-level scientist within three working years of completing their PhD.

3.3 Infrastructural capacity

It was strongly recognized that more scientific infrastructure was needed to improve the scientific research and associated activities in the MANGO region, and also to help foster the capacity development of the ECS and regional collaboration of MANGO scientists. As mentioned above, common issues across the MANGO region have been raised. However, its severity differs from country to country. In some countries, atmospheric chemistry was not perceived as an important concern compared to water quality, which was seen as a more "visible" environmental issues associated with "direct" health risks. This was linked to the small number of atmospheric scientists and poor networking of local scientists in the country and affected the level of overall scientific activities and contributions to society. In some countries, national funding was minimal, affecting the level and amount of instruments/equipment for atmospheric chemistry research. "Which is lacking between observational or experimental instruments and modelling or theoretical tools?" was an interesting question. Some countries needed observational or experimental instruments, but some modelling or theoretical tools. However, the most important message was the importance of strengthening fundamental science in "both" ways.

With respect to observational infrastructures, many scientific instruments are costly and complex to operate. We highlighted the great potential of easy-to-operate instruments, with affordable cost for the Asian region, in a variety of research including domestic pollution hot spots, biomass burning, and trans-boundary long-range transport.

The importance of investigating air pollution and health issues in Asia was emphasized earlier. Air pollution, especially aerosols, considerably contribute to human health risks. Millions of deaths worldwide are attributable to PM2.5 (fine aerosols), which is potentially a human carcinogen and a major environmental health concern. Especially in Asia, rapid economic growth has taken its toll on human health. It was estimated that 2.2 million of the world's 7 million premature deaths each year from household (indoor) and ambient (outdoor) air pollution occur in Asia or the Pacific, which roughly coincides with the MANGO region ("Air pollution", 2018). Among the 2.2 million air pollution-related deaths in this region in 2016, 29% were due to heart disease, 27% by stroke, 22% by chronic obstructive pulmonary disease (COPD), 14% by lung cancer, and 8% by pneumonia. The health impacts of PM2.5 could be classified into acute and chronic effects. Chronic health impacts, such as COPD and lung cancer, are associated with long-term exposure. In contrast, acute health impacts such as asthmatic attacks and irregular heart conditions are directly associated with peak exposures, which are difficult to measure up to now. As the Asian population is exposed to considerable levels of PM2.5 compared to the rest of the world, research on the impacts of air pollution on health is necessary for Asia.

Emerging new technologies such as low-cost sensors (LCS) may assist Asian scientists to tackle the challenges and provide scientific evidence to set short-term standards to reduce health risks of acute effects. By taking advantage of these technologies, we have started a joint research project entitled "Health Investigation and Air Sensing for Asian Pollution (HI-ASAP)" led by Shih-Chun Candice Lung (Taiwan ROC), in collaboration with scientists from 13 countries.

3.4 Current issues and future challenges

We analysed the current issues, causes, and gaps in science, communication and collaboration, and early career capacity building based on what was actually working well in promoting early career capacity building. We also discussed potential ideas for short-term as well as future improvements.

The commonly identified issues are listed below:

1. Geopolitical issues;
2. Cultural differences in the workplace;
3. Lack of connection between ECS and established scientists;
4. Lack of connection among established scientists;
5. Lack of understanding of regional atmospheric chemistry issues (e.g., air quality, waste and agriculture, biomass burning);
6. Difficulty or challenge in connecting modelling, field measurements and laboratory studies;
7. Lack of funding;
8. Lack of awareness of available opportunities;
9. Lack of academic courses at both graduate and undergraduate levels; and
10. Lack of regional cooperation or policy discussion to control transboundary air pollution (e.g., winter haze in the IGP region).

Given these issues, we identified some important points to be implemented to promote fruitful scientific collaboration:

1. Equal opportunities for all partner institutes;
2. Gender balance;
3. Participation of ECS in collaborative activities;
4. Promotion of science and awareness beyond geopolitical differences;
5. Data and knowledge sharing through joint publications and collaborative projects;
6. Joint publications and white papers for policymakers;
7. Regularly sharing information, limitations, and experiences; and
8. Follow-up meetings to review the science questions, identified issues, and other aspects.

We emphasize that MANGO can be a trusted platform that facilitates collaboration, as certain countries sometimes do not allow international collaboration. In contrast, international institutions/organizations are neutral platforms in which researchers from conflicting countries can also interact and establish international collaboration. We also find that MANGO can provide a platform for ECS to share their ideas, find potential supervisors to pursue higher degrees, and find good mentors and spokespersons representing each country.

To further improve capacity building of ECS, we realized that greater awareness of opportunities for ECS is facilitated through multiple media such as webinars, online courses, multidisciplinary workshops and internships, as well as a widely distributed news bulletins and newsletters.

4. CONCLUSIONS

We have established the IGAC–MANGO platform with the principal objective to enhance the capability and capacity of air quality research, with emphasis on its links to human health and climate change, including the components of trans-disciplinary collaboration. In total, 17 countries are involved in MANGO, namely Australia, Bangladesh, China, Hong Kong, India, Indonesia, Japan, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan ROC, Thailand, and Vietnam. By overseeing the scientific activities in the region and holding scientific workshops and capacity-building activities, including training courses for ECS, we have facilitated the collaboration between Asian and international scientists and accelerated the development of the next generation of scientists in this region. The project is expected to yield several fruits, including new leaders from Asia in international committees, enhanced interactions between Asian scientists resulting in joint research proposals, and increased opportunities for ECS to pursue their research with international scientists.

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Participatory methodologies enable communities to assess climate-induced loss and damage

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ABSTRACT

Opportunities to strengthen resilience can be limited, as the adverse impacts of climate change become more severe. In these cases, it is recognized that there are limits to adaptation and that communities are facing loss and damage as a result of climate change. The perspectives of communities most vulnerable to climate change impacts—in particular those of marginalized sub-sections of communities whose voices and perspectives may be inadequately represented—should be reflected in processes that assess loss and damage and that facilitate relief, support and compensation for those affected. Unfortunately, community dynamics can often hold back women and marginalized community members from participating in or benefiting from assessment processes, resulting in under-reporting of their losses. Participatory processes such as the collective development of maps and calendars can be effective tools for communities and marginalized sub-sections to gather, understand, analyze and act on information about the climate impacts that they are experiencing. These processes can form the basis for accurate assessment of the economic losses and damages suffered. Research initiatives must also avoid the risk of leaving community members with disturbing new questions about the challenges they face, without also leaving them the means to understand the issues and take action. Through the course of this research, a number of participatory tools were adapted to the context of climate-induced loss and damage, trialled, reviewed and improved. This has resulted in the identification of methodologies that can be used for the specific purpose of community-led assessment of climate-induced loss and damage. The methodologies have been published in a Handbook for Community-Led Assessment of Climate-Induced Loss and Damage by ActionAid International, the Asia Disaster Risk Reduction Network (ADRRN) and Climate Action Network South Asia (CANSA) with the support of the Asia-Pacific Network for Global Change Research (APN). The participatory tools in this 7-step guide can be used by communities to assess the losses and damages they have experienced and to understand the trends and future changes that climate change may bring. They can use the participatory analysis to initiate strategic planning to reduce vulnerability to future potential losses, and request support from authorities.

KEYWORDS

Adaptation, Climate change, Community, Gender, Loss and damage, Marginalized communities, Participation, Participatory methodology, Resilience

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HIGHLIGHTS

» Assessments of loss and damage impacts must reflect the perspectives of vulnerable people.

» This participatory methodology to assess loss and damage enables vulnerable communities to engage.

» It facilitates the understanding of climate change trends and action to address future disasters.

» Communities gather evidence, give information and can request relief, support or compensation based on their own analysis.

» The methodology is not extractive, but inclusive and empowering for marginalized communities.

1. INTRODUCTION

1.1 Climate-induced loss and damage and the limits to adaptation

In recent years, the world has strengthened efforts to undertake climate change adaptation (CCA) and disaster risk reduction (DRR) for communities vulnerable to climate change impacts. However as indicated in the IPCC Fifth Assessment Report (IPCC, 2014) Working Group II section on climate impacts, loss and damage from climate change are occurring with increasing frequency, due to limits to adaptation and insufficient mitigation efforts. Climate-induced loss and damage can be brought about by extreme weather events as well as slow-onset events. Losses caused by rising global average temperatures can include lands lost to rising sea levels or desertification, or incomes lost to crop failure. Damages caused by climate change can include the cost of rebuilding homes destroyed by cyclones or the costs of replanting trees destroyed by typhoons.

With the recent publication of the IPCC Special Report on 1.5°C, (IPCC,2018) there is a growing body of scientific evidence of the losses and damages that vulnerable countries will face as a result of climate change (Mechler, James, Wewerinke-Singh, & Huq, 2018). A lack of published literature on the specific impacts of loss and damage on vulnerable countries in AR5 has, however, been noted (van der Geest & Warner, 2015).

1.2 Understanding the impacts of climate-induced loss and damage on marginalized communities

When disasters take place, including climate disasters such as floods or cyclones, NGOs and aid agencies already use a range of tools to assess their impact. Existing practices include questionnaires, observation or focus group discussions, and are often undertaken by professional researchers visiting the community in the aftermath of a disaster. These approaches can certainly serve to identify many significant loss and damage impacts faced by communities. However, community dynamics can often hold back women and marginalized community members from participating in the assessment processes (Rashid & Al Shafie, 2009).

As efforts continue to map these impacts, the particular focus must be to understand the perspectives of communities most vulnerable to its impacts, and in particular of those marginalized sub-sections of communities whose voices and perspectives may be inadequately represented.

Women and marginalized community members such as elderly or disabled persons, poor people or minority groups suffer climate change impacts first and most severely, due to a combination of reasons including gendered roles, their lack of access to information, skills, services, resources or secure land tenure that help to strengthen resilience. For example, extension services and advice are often targeted at male farmers growing cash crops, and ignore women farmers growing crops for families and local markets (Anderson & Marcatto, 2018). When rains and crops fail and water sources dry up, women and girls often end up walking much further to fetch water, skipping meals, dropping out of school or experiencing gender-based violence from their husbands. In times of extreme food scarcity, increased numbers of women may resort to sex work to raise money to feed their families, increasing their risk of contracting HIV (Anderson & Curtis, 2016). Women often face difficulties in accessing secure land tenure, which serves to discourage them from making necessary investments to strengthen resilience (IPCC, 2019). However, the perspectives of these same vulnerable community members can often be missing from research and analysis, due to a combination of factors including their lack of understanding of climate change, low status in the community, or lack of confidence to speak to researchers and their peers.

This means that if research methodologies do not actively address and compensate for these inequalities, the information they gather may be biased towards the perspectives of men, and those in the community with status, wealth or education, i.e. those who will feel more confident to share their perspectives with researchers. There is thus a risk that analysis of climate impacts and loss and damage, and strategies to address these, can miss the full story and in particular the complex issues faced by women and marginalized community members.

Furthermore, questionnaires, when used on their own, may not themselves serve to empower the community. If external professionals undertake the research, analysis and advocacy on the community's behalf, the community themselves may miss out on the opportunity to reflect and learn from their experiences.

1.3 Participatory approaches for community assessment of climate-induced loss and damage

ActionAid has years of experience in developing programmes with communities on climate change-related issues including disaster risk reduction, agriculture, adaptation and resilience (Anderson & Curtis, 2016; Sterrett, 2016). Participatory methodologies that include particular efforts to ensure the effective participation of women and marginalized community members have been a key component of this work, to ensure that strategies are developed based on a comprehensive and inclusive understanding of local context. Based on this experience, collective community discussions that actively seek to strengthen women's empowerment and participation, have resulted in community members having a more accurate, comprehensive and effective analysis of their situation, including any changes that have taken over time, and the challenges and opportunities that these present. Participatory and inclusive methodologies can lead to more accurate and effective research outcomes than questionnaires alone. This holds especially true for the issue of climate-induced loss and damage, which is likely to exacerbate vulnerabilities and impacts faced by marginalized community members.

With support from APN, ActionAid, in collaboration with Climate Action Network South Asia (CANSA) and the Asian Disaster Reduction and Response Network (ADRRN) have thus developed a "Participatory Methodology for Community Assessment of Climate-Induced Loss and Damage," (Anderson, Hossain, & Singh, 2019) to complement the organizations' existing programme work on resilience and to enable assessment of losses and damages faced by vulnerable community members. ActionAid worked with its offices in 5 countries: Bangladesh, Cambodia, Myanmar, Nepal and Viet Nam; and collaborated with CANSA and ADRRN to develop, pilot and refine the set of tools in the methodology.

Participatory practices in which community members draw, discuss and debate the outcomes together, can help them to see, remember and benefit from the insights and analysis, and for collective knowledge to leave its mark long after the external researchers have left. The participatory process can itself empower and strengthen solidarity. It encourages community members to use their knowledge to be active agents who by working together can plan, organize and better shape their futures and that of their community.

Communities can then use the information collected during the process, for several purposes, including:

- Understanding climate change trends and taking action to avoid or reduce future disasters and losses;
- Giving clear information to local and national authorities to help them understand and map the trends and impacts of climate disasters, and to plan to avoid future disasters;
- Engaging with the government to request relief, support or compensation based on the assessment;
- Compiling evidence of climate-induced loss and damage so that national governments can request support from the international community

The methodology is presented in an easy-to-understand "handbook" format to be used by development practitioners. Its seven steps use different tools through which a community can identify the losses and damages they have experienced from disasters, particularly climate change disasters. Most of the steps and tools are participatory to be used by the community together. One of the steps is a process to interview individual expert stakeholders such as local authorities, disaster management experts and climate scientists, thus enriching the community analysis with expert knowledge.

2. METHODOLOGY

2.1 Objective of the project

The primary objective of the project was to develop a set of "tools" for a Participatory Methodology for Community Assessment of Climate-Induced Loss and Damage, which would specifically facilitate the inclusion and voices of women and marginalized community members. This was to be done through a process of identifying the key issues arising from Loss and Damage, adapting existing participatory methodology to that context, testing, reviewing and refining the methodologies.

2.2 Data collection and literature review (Phase 1)

The project proceeded in two phases, known as Phase 1 and Phase 2. In Phase 1, a multi-stakeholder methodological approach was developed to incorporate scientific evidence with field-level data collection, integrating qualitative and quantitative information of L&D from a national, community and household perspective. This was complemented with a review of existing literature and mapping of national institutions. Primary data was gathered from Focus Group Discussions (FGDs), Key Informant Interviews (KIIs) and household interviews.

Field research activities included scientific data collection about temperature scenarios and their impacts on rising sea levels, glacial lake outburst floods (GLOFs), floods and droughts, as well as field observations and in-depth community level interviews and discussions to incorporate remote communities into the assessment of risks supported by scientific analysis and their experiences.

Case studies were developed to understand the realities of climate-induced loss and damage in various geo-climatic zones in Asia. FGDs were held with community groups. A simple questionnaire format was used for individual community members. The questionnaire had already been developed before the initiation of the APN project, by the London School of Economics (LSE) with input from ActionAid, covering a range of

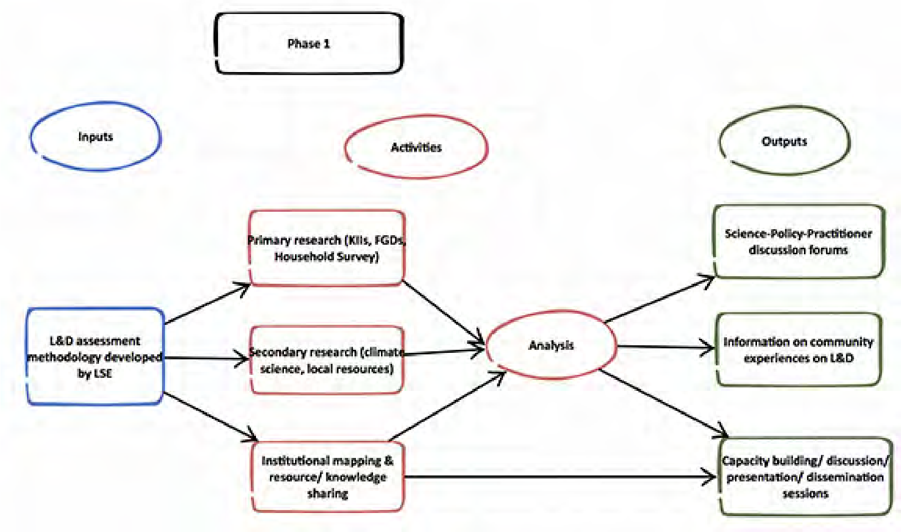

FIGURE 1. Flow chart: Phase 1.

issues and challenges that are potentially being faced by communities as a result of climate-induced loss and damage. While the questionnaire format was not the final product outcome for the project, its use in Phase 1 contributed towards identifying and/or confirming the general direction and critical issues arising as a result of climate-induced loss and damage.

Seven communities covering a range of geo-climatic contexts in five countries (Bangladesh, Cambodia, Myanmar, Nepal and Viet Nam) were selected for trialling the methodology in Phase 1. Community members (including women and marginalized community members) responded to the 50 questions in the initial questionnaire for Phase 1 (which gathered extensive detail on issues such as family assets, livelihood sources, income and effects of changing weather patterns on these), participated in community FGDs, and participated in the development of case studies, led by research fellows working with ActionAid in 5 project countries.

An assessment of the content, issues, practicalities and limitations of the questionnaire process was undertaken, which also drew from insights provided by ActionAid programme officers in 5 countries.

2.3 Developing a participatory methodology for the assessment of climate-induced loss and damage (Phase 2)

For Phase 2, the development of the "tools" for the Participatory Methodology was led by ActionAid Bangladesh, with support from ActionAid International and feedback from ActionAid offices in the four additional countries as well as CANSA and ADRRN. Issues identified in Phase 1, including food security, livelihoods, safety, migration trends and non-economic loss and damage from a range of climate-induced shifts such as changing rainfall patterns, droughts, floods, cyclones and rising sea levels formed the basis of discussion themes.

Pre-existing methodologies developed earlier by ActionAid such as community mapping, seasonal calendars and risk indexes were adapted to the issues surrounding climate-induced loss and damage. Methodologies or "tools" were developed to draw out community members' observations on local climate change impacts, how these have affected and changed the communities' realities over the last decade or more, and how and where specific geographic locations or community members are particularly vulnerable. The tools can enable the community to work together to map resources, infrastructures, livelihoods, hazards, changes in seasons, impacts and changing trends, to build up a clearer picture of the historical changes that have taken place and the scale of the impact.

The methodologies developed in Phase 2 share a strong emphasis on collective discussions and visual tools to facilitate deep reflection and vibrant discussions, particularly from community members such as women and marginalized people who may typically be less outspoken in community meetings. The participatory tools are designed to enable all members of the community to participate actively, to speak up and share their view or experiences, and to learn together. For example, to encourage the participation of community members who cannot read or write, the drawing of community maps on flip charts with symbols of key landmarks and infrastructure facilitates more inclusive participation. Alternatively, some communities may feel more comfortable drawing directly onto the earth using a stick, leaves, twigs or local materials as symbols to represent areas of the map.

The tools were then trialled in the five participating

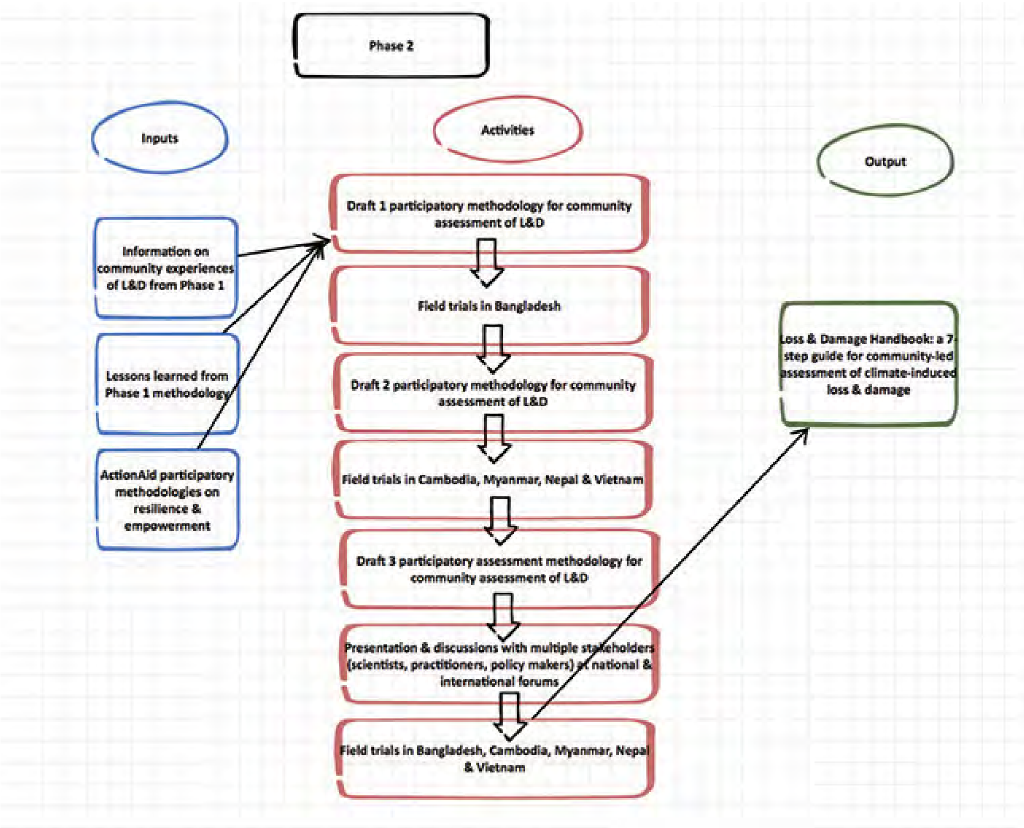

FIGURE 2. Flow chart: Phase 2.

countries, with feedback provided to continue refining the methodologies. In Nepal, for example, one of the villages where the methodology was tested was in a small community of Musahar people, considered to be one of the lowest castes of the Dalit groups in the area, and thus highly marginalized (Sunam, 2014). The village was severely affected by flooding in 2017, with houses destroyed and the community temporarily displaced. ActionAid Nepal had earlier provided relief to families in the village at the time of the disaster, and many were still waiting for support from government and NGOs to reconstruct their homes, resettle in more secure areas, and to restore their livelihood opportunities. The village was, therefore, a highly vulnerable community and an appropriate test case for the methodology.

Based on the feedback from the trials in the various countries, ActionAid Bangladesh worked with ActionAid International to write up the set of "tools" into a Draft "Loss & Damage Handbook: A 7-step guide for community assessment of climate-induced loss and damage". The draft Handbook was reviewed at national and regional meetings of scientific, policymaker and practitioner experts including from the five trial countries, who provided feedback for its further refinement. The five countries then tested elements of the Handbook for another round of feedback, which then fed into the final Handbook.

3. RESULTS AND DISCUSSION

3.1 Principle findings from Phase 1

The two distinct research Phases resulted in specific and distinct lessons and recommendations, building towards the outcome of a participatory methodology for community assessment of climate-induced loss and damage. Phase 1 and its results and lessons served to focus on the direction and effectiveness of Phase 2.

The questionnaire in Phase 1 confirmed that climate change is causing both economic and non-economic loss and damage, the latter including loss of ecosystems, social ties, cultural and sacred sites and associated practices. Vulnerable communities and households are being affected by loss and damage, including the displacement of homes, people's physical safety, their agriculture, fishing, food security, livelihoods, health and access to fresh water, and is leading to migration. Furthermore, many communities are a long way from implementing or accessing risk management systems that are sufficient to avoid potential loss and damage, due to a lack of resources, knowledge and institutional support.

However, the use of detailed questionnaire surveys was not found to be a reliable or effective sole means of calculating individual household or community-wide losses and damages, due to cultural and logistical barriers. If done in a way that works for the participants' needs, questionnaires can play a role, but they are not sufficient to get a full and accurate picture of the qualitative and quantitative impact of climate change on communities.

The limitations of the Phase 1 questionnaire exposed how, in certain communities, cultural pressures can prevent women from talking to strangers, thus inhibiting researchers' access to women's perspectives when undertaking questionnaire surveys. To effectively assess the impacts of climate-induced loss and damage, therefore, participatory processes are needed, to enable women and marginalized voices better to participate more effectively. Strategies could include sub-dividing community discussions into groups of women and men so that women feel able to speak more freely and to openly discuss the gender-specific challenges they face including lack of access to education, services and resources, or gender-specific roles such as fetching water and firewood or feeding and caring for children and elderly relatives.

Logistical barriers such as the realities of daily life, picking up children, feeding livestock etc. can also prevent community members from completing a long and detailed questionnaire. If used, questionnaire formats should therefore aim to be as short and simple as possible. Questionnaire formats should also allow for responses that do not fit within multiple-choice options. The questionnaires should not be too long or too complex for effective data entry.

Another lesson was that if communities have not yet had the chance to learn about climate change or to reflect on how it has changed their lives, this can also limit the quality and accuracy of responses. Where possible, therefore, discussions on climate-induced loss and damage should be combined with programmes working with communities to strengthen their resilience so that communities can already understand climate change issues when they come to discussing and assessing the quantitative and qualitative scale of loss and damage. To be effective in communities that have not yet had discussions about climate change and disasters, a process to build community understanding and orientation of climate issues is required, and this must be intrinsic to the research methodology.

A further observation from Phase 1 was that when used alone, questionnaires do not serve to empower or strengthen the agency of the community members to deal with the issues that they face. Therefore questionnaires, if used, should be combined with approaches that strengthen the empowerment of women and marginalized community members, so that ultimately the community can advocate for policies that address the issues raised. The need for participatory tools similar to those already used in ActionAid resilience programming was confirmed, to encourage open discussion, and to build knowledge and empowerment, as part of the process in which information is collected, and analysis is facilitated.

Phase 1 further concluded that inclusion of tools to enhance understanding of climate-induced migration as a result of loss and damage would be appropriate and timely considering the increasing prominence of this issue and its growing impact on communities. Migration is likely to be a growing consequence of climate-induced loss and damage, and communities, development practitioners, policymakers and academics will increasingly require tools to understand its scale and impact, to inform programming and policy.

As a last point, project staff observed that the sustainability of future projects of a similar nature could be enhanced through the use of a staff member to implement the project and institutionalize learning through the process, instead of relying on a research fellow who would need to leave after the project has finished.

3.2 Principle findings from Phase 2

In Phase 2, the lessons from Phase 1 were put into practice and a participatory methodology for community-led assessments of climate-induced loss and damage was developed. Through the course of adapting, trialling, reviewing and improving the tools for the participatory methodology, Phase 2 confirmed that participatory approaches are effective in facilitating community engagement and understanding, and in identifying the right information for the assessment of climate-induced loss and damage, including gendered impacts of climate change. Indeed, the project showed that communities appreciate the opportunity to use the participatory process to build their knowledge and understanding of the issues their face and to increase their ability to engage with policymakers and experts for greater impact and potential to address the issues identified in their analysis.

Through the process of trialling and refining the tools, Phase 2 revealed that an effective participatory methodology for community assessment of climate-induced loss and damage requires multiple steps and tools in a process that can span days, weeks or months. Visual tools that community members can collectively design and input towards such as maps, calendars and collective trend analysis, are particularly useful in the community context and for building people's understanding of how their lives are being affected by climate change.

The methodology developed aims to complement and strengthen the communities' own experience-based knowledge, with external knowledge and a deeper understanding of the causes of climate change, as well as to identify potential opportunities for interventions and advocacy. Phase 2, therefore, led to the addition of a step in which key informant interviews (KIIs) with external experts, are carried out by NGO staff, and the findings then reported back to the community, followed by presentations and discussions further unpacking of climate change and loss and damage issues. This approach was found to be an effective way of complementing and combining the community's insights with external knowledge.

The repeated testing phases of Phase 2 showed that in order for the community to be able to effectively calculate the economic impacts of loss and damage and to broaden their understanding of non-economic impacts, careful sequencing of steps is vital. Participatory and visual tools such as hazard mapping and calendars are a necessary first step, enabling the community to gain an understanding of climate trends, reflect on the changes felt at the community level. These insights can then be complemented with external knowledge of climate change and its causes. Following these steps, the community are then in a better position to more effectively calculate the climate-induced losses and damages they have experienced. Tools for this step include a combination of group discussions and individual household questionnaires.

Consistent with ActionAid's objectives of empowering communities to use their knowledge to plan and take action, the methodology now also includes a step to encourage community members to take the information and evidence to relevant agencies and local, national or international governments leads. This is so the process of assessing loss and damage can really result in beneficial impacts on the communities' lives. This step helps community members to translate the findings that they have gathered through implementing the participatory methodology, into claims for financial support from relevant actors and authorities to compensate for the losses and damages they have suffered. Advice on strategies that can help them advocate for the protection of their rights can enable them to improve their circumstances in the face of the climate impacts that they are suffering.

Overall, Phase 2 confirmed that this approach to participatory research provides the most significant value towards supporting the socio-economic development of communities. We note that the gathering of data for academic publication is not the primary objective of this approach.

Indeed, after the thorough process of testing and refinement, communities and ActionAid staff felt pleased with the results and the handbook that was developed. As one programme officer from Myanmar commented: "The handbook is simple and easy to understand for communities. It is participatory, and it gets the right information. We look forward to using this process to do further assessments of climate-induced loss and damage to other communities."

3.3 Seven steps for community-led assessment of loss and damage

Six of the seven steps developed in the Handbook are participatory, drawing from the community members' own knowledge and experiences. In the majority of cases, an NGO or a local Community Based Organisation (CBO) will take the lead in organizing the process, facilitating the discussions, and supporting the community to present their analysis to relevant decision-makers.

The resulting Handbook thus has the following key steps and tools: 1) "Mapping of Risks and Resources" to highlight the geophysical changes taking place in the village as a result of climate change; 2) "Seasonal, Agricultural and Livelihood Calendars" to highlight how climate change is affecting seasonal weather patterns and the impacts on farming, fishing and livelihoods, and how these impacts affect women, men and marginalized community members differently; 3) "Hazard Risk Index" to identify which family homes and community infrastructures are most vulnerable to disasters such as floods, cyclones or landslides; 4) The information in those tools is then put together for a collective process of "Trend Analysis", a key process for enabling insights and understanding about climate change impacts, including gendered impacts; 5) Step five complements the community's own information with external expertise. "Key Informant Interviews (KIIs)" are held with external experts such as scientists, local government representatives on climate change, and representatives from the departments of meteorology, DRR, agriculture, etc. The communities' maps and calendars are shared with the experts for comments and/or confirmation. The KII findings are then reported back to the community for the deepening of their understanding of the issues. The international context and definitions of loss and damage are then presented, facilitating a discussion relating this to the local realities. 6) Step six "Calculating and Reporting Loss and Damage" uses the qualitative understanding of climate change now gained by the community, to develop a quantitative assessment, and to confirm, update and collate information for reporting purposes. Simple household and community-level questionnaires are undertaken to identify the monetary value of damages and losses experienced as a result of climate change impacts. Discussion is also held about migration and displacement as a result of climate-induced loss and damage. The findings of the previous process are collated onto a table of costs, and a new map of risks and resources is drawn to point the way forward for reducing risks and strengthening resilience. 7) The final step "Advocacy and Lobbying" is for the community to take the information and evidence to the relevant duty-bearers, including local, national or international governments or relevant agencies.

4. CONCLUSIONS

Climate change is changing lives and livelihoods in communities around the world, and this is especially true for poor and rural communities in vulnerable countries. These vulnerable communities have done the least to contribute to the global climate problem, but they suffer its impacts the most, including the impacts of climate-induced losses and damages.

When NGOs and CBOs engage with communities to assess the impacts of climate-induced loss and damage, they must do so in a way that is both effective and empowering. Efforts must be made to understand and address the social realities and barriers facing those communities and the sub-sections of those communities when trying to understand and articulate their experiences of climate-induced loss and damage. This must be done on the community members' terms so that they can better engage with the research processes. Additionally, research initiatives must avoid the risk of leaving community members with disturbing new questions about the challenges they face, without also leaving them the means to understand the issues and take action.

For communities to effectively claim relief, support and compensation from local, national or international governments, they need to be able to record and provide evidence of the loss and damage that they have suffered. It is important that the process to calculate these losses and damages is collective and inclusive so that all perspectives are reflected in the record. To build an accurate and fair picture of real vulnerabilities, risks and impacts, the process must empower and include women and marginalized community members.

NGOs and CBOs must therefore address these concerns by facilitating participatory processes that empower the community, particularly women and marginalized community members. By working together to map resources, infrastructures, livelihoods, hazards, changes in seasons, impacts and changing trends, community members can build up a clearer picture of the historical changes that have taken place, and the scale of the impact.

A participatory methodology for community-led assessment of climate-induced loss and damage can enable communities to gauge and increase local awareness of climate change, loss and damage and the gendered impacts, to trigger discussions and strategies to build resilience; to identify the limits to adaptation strategies and to assess the real impacts of loss and damage on the ground. This approach can be powerful because community members themselves become the principal investigators and analysts. Moreover, this approach can be used as a way to identify key areas for engagement with local, national and international authorities for considering and addressing climate-induced loss and damage. NGOs and CBOs can adopt these methodologies and facilitate community discussions using the tools outlined in ActionAid's Loss & Damage Handbook (Anderson, Hossain, & Singh, 2019).

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