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RESEARCH ARTICLE

DECISION SUPPORT SYSTEM ENABLED DIGITAL MOBILE PLATFORM TO ASSIST FARMERS TOWARDS AGRICULTURAL PRODUCTION SUSTAINABILITY IN SRI LANKA

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ABSTRACT

Various issues in crop production and related industries pose significant impediments to economic growth and food security in Sri Lanka. The key issue identified in the agriculture sector is the lack of access to relevant and timely information in a format that is actionable and context-specific. However, information and communication technology (ICT) has the potential to address these gaps and revolutionise agriculture, as it has done in many other countries. The study employed the Design Science Research (DSR) approach to develop innovative artefacts that provide vital information to farmers during crop production. This paper demonstrates various iterative steps in the artefact construction and evaluation processes and shows how context-specific, relevant and actionable information represented through the user interfaces of two mobile applications: "*Govi-Nena* Farmer" and "*Govi-Nena* Home Gardening". The study further elaborates how the key challenges were addressed and how the conceptual solution was proven to work in a real-world scenario with the evidence of knowledge satisfaction analysis using the 5-point Likert scale method with 32 app users. The works initially modelled crop and variety selection based on agro-ecological regions (AERs), seasons, and pre-planting and cultivation activities of the farming life cycle. Packages of practice (PoP) workbooks were then developed, tailored to the farmer's context using these models. The analysis of PoP knowledge revealed that every user was satisfied ($p<0.05$) with the information provided in the app, especially data accuracy ($Z=4.221$), fertilizer application guidelines ($Z=4.170$) and information quality ($Z=3.785$), all of which reached a very high level of satisfaction. Hence, the PoP enabled decision support system has been embedded into the ontological crop knowledge base of the mobile-based systems to assist farmers in making timely quality decisions to achieve target goals.

Keywords: Crop yield, Decision making, Design science research, Digital extension system, Home Gardening, Information gaps, Mobile application, Packages of practice, Sustainable agriculture

INTRODUCTION

The global human population continues to grow and currently approaching 8 billion (United Nation 2022). Almost half of the population lives in rural areas, and the majority is dependent on agricultural production around the world (FAO 2019). To combat world hunger and improve rural livelihood, enhancing the sustainability of farming systems is a vital concern (Armstrong *et al.* 2011). Sri Lanka is a unique tropical island in the Indian subcontinent, and agriculture is one of the key sectors of the country's economy. According to the World Bank (2020), 81.3% of Sri Lankans inhabit rural areas and among them, over 72% rely on farming activities for their principal livelihood. However, only 10.2% of the country's Gross Domestic Product (GDP) is generated from the agricultural sector (DCS 2022). Crops, livestock, fisheries and aquaculture, and forestry were the different segments of the industry, and the crop division is one of

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the key segments in the agriculture domain. Because food prices are increasing rapidly with the decreasing rate of crop development (Rosario and Potts 2016 and World Bank 2017). Henceforth, enhancing crop production is vital for the rural economy to elevate the farmers' wage rate and social status and for the provision of food for the growing population and reducing rural poverty (Samarakoon and Shamil 2010; Rosario and Potts 2016).

Decision-making is a crucial aspect of almost every field, including the agriculture sector, and it heavily impacts the final quality of products or services. In crop production, farmers have to make many decisions in each season of the farming process, considering profitability and productivity. Farmers' decisions are the core of farm management (Dury *et al.* 2012). At the beginning of the farming life cycle of the crop production, the common question that arises among the farmers is "What are the suitable crops to grow?". To find a better solution, they should consider critical factors such as location-based environmental conditions, special characteristics of the crop, what other farmers are growing and in what quantities, market information, resource availability, and preference (Walisadeera *et al.* 2014). In addition, the cultivation timing and extent depend on the availability of labor and water, seasonal rainfall pattern and market demand (Kotera *et al.* 2014). Similarly, crop yield is one of the fundamental matrices used in agriculture, and the differences in yield are not only relied on crop types but are determined by a variety of factors (Wilbois and Schmidt 2019). The yield can be categorised into three production levels: potential yield (PY), attainable yield/ economic yield, and actual yield/ farm yield (Figure 1). PY is known as the high-end scale of the yield or the yield to be assumed with the best-adapted variety with the best agronomic practices, necessary inputs, and without biotic and abiotic stresses. Attainable yield is the yield attained by a farmer using average natural resources, inputs and optimum practices while facing weather changes. Farm yield (FY) is the central yield (field, district, regional, or national average yield) achieved by farmers under existing management practices and soil properties (Fischer *et al.* 2014; Tadele 2017). Yield potential is determined by growth defining factors (Figure 1: Refer level a), for instance: location, crop-sowing date, maturity rating, genetic and crop characters (Rabbinge 1993; Ortiz-Monasterio *et al.* 1994; Tadele 2017). Factors such as nutrient and water limitation that influence a reduction in yield from potential to attainable are called growth limiting factors (Figure 1: Refer level b). The actual yield is lower than the attainable yield due to the influence of growth reducing factors (Figure 1: Refer level c) such as pests, diseases, and weed pressure (Rabbinge 1993). Hence, focusing on those factors during decision making can lead to many benefits. Further, delays in some agricultural activities such as preparation of seedbeds, planting, and harvesting could cause crop failure and reduce harvests (Sawano *et al.* 2008). Although due to the lack of information visibility, farmers tend to make incorrect decisions at each stage of the crop production cycle, resulting in unsatisfactory yield or less demand at the market level and inconsistent economic gain (De Silva *et al.* 2013; De Silva *et al.* 2012).

Farmers usually seek advice from extension services for their cultivation issues. In Sri Lanka, both public and private sectors deliver agricultural extension and advisory services to the farmers. Nevertheless, the current human-driven extension system has failed to meet farmers' expectations, as it often cannot provide timely information for urgent needs (Walisinghe *et al.* 2017; Wanigasundera and Atapattu 2019). In general, an Agricultural Instructor (AI) is responsible for a division comprising several villages, and they must cover over 1700 farmers. Most farmlands are in rural areas, making it difficult for AIs to interact with farmers due to proximity challenges. Furthermore, slow adjustments in responding to a range of issues, declining investments in the extension system, and the increasing performance gap due to the failure of bringing research outcomes to the farmer fields were other drawbacks in the present scenario. Therefore, the system becomes less effective and incapable of fulfilling the exact requirements of farmers (Lokeswari *et al.* 2016; Lamontagne-Godwin *et al.* 2017; Wanigasundera and Atapattu 2019). As a result, farmers rely on their own decisions to overcome issues, but such efforts often result in failure or partial resolution. Consequently, obtaining reliable knowledge and making decisions with advanced tools can be considered the most effective approach to ensuring the sustainability of agricultural production.

With the predominance of the digital era, ICT acts as a catalyst and creates value through efficiency, reliability, speed, ease of use, confidentiality, and versatility. However, there was a gap between the technology currently used by farmers and their preferences. Therefore, providing facilities with innovative and efficient technology at an affordable way is a vital prerequisite to enhancing ICT usage by farmers (Armstrong *et al.* 2012). Among the ICT-based applications, the rise of mobile phones has been one of the most impressive changes in developing countries over the past decade (Goundar 2010). Recent statistics indicate that there are 11.34 million Internet users and 32.29 million mobile connections in Sri Lanka. The number of mobile connections increased by 1.0 million (+3.2%) between January 2021 and January 2022. Hence the total mobile connections up to January 2021 were equivalent to 149.9% of the total population in Sri Lanka (Kemp 2022). Therefore, the usage of mobile phones is high compared to other ICT-based applications. The most clear-cut way that mobile phones reduce time and unnecessary costs to improve accessing and disseminating information is by helping farmers to boost their income and eliminate intermediaries (Aker and Mbiti 2010; Chavula 2014; World Bank 2017). All levels of disaggregated literacy (by sex, sector and by age group) show a higher level of digital literacy (57.2%) than computer literacy (34.3%), reflecting the transition from personal computers to smartphones and tablets (DCS 2021). Currently, mobile apps are being used globally for different purposes and solve complex problems efficiently and effectively. In agriculture, mobile apps allow farmers to access real-time information in one place even if they are miles away from the crops (Kuharic *et al.* 2017). Hence, well-developed mobile-based apps in the farmer context help to make quality decisions promptly and increase the growth of agriculture production more efficiently. Besides, enhancing the quality of information in the apps related to the critical aspects of the decisions will help minimise the major challenges faced by the farmers.

The main aim of this study is to determine the potential for improving the yield and long-term sustainability of crop production using ICT-based mobile solutions. Hence, the key factors contributed to yield gaps and ecosystem services identified in conventional and organic farming. The artefacts have addressed those limitations to enhance and secure

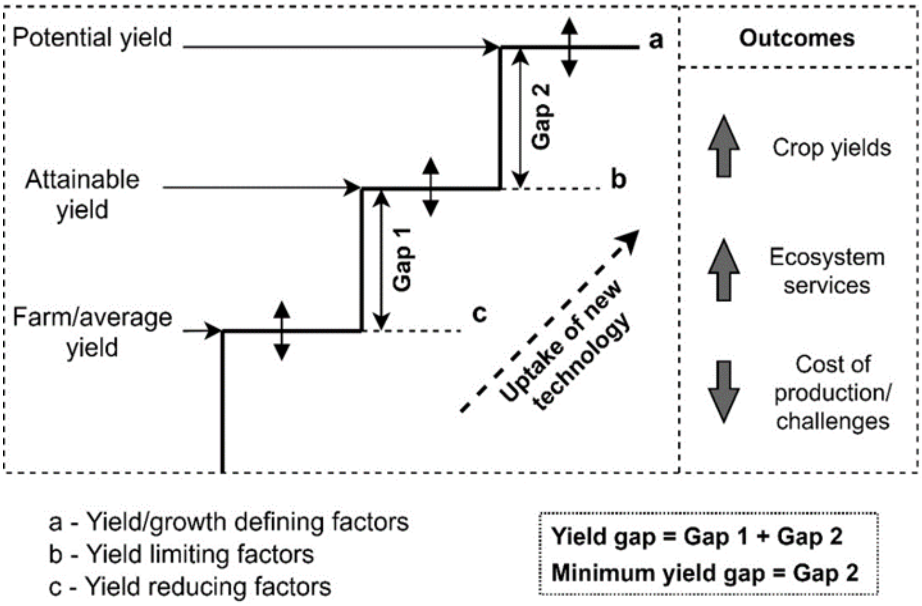


Figure 1: Conceptual model for a sustainability approach (Tadele 2017)

yields,and reduce unnecessary costs and environmental degradations. Especially in the current system, most farmers are not aware of the right pathway to fulfilling their needs, and the absence of relevant and timely information leads to incorrect decisions at different stages of crop production. As a result, the outcomes gained will not sustain in the long run. Henceforth, this work targeted the following objectives: firstly, to design a model to support the selection of agro-ecological regions based on recommended crops and varieties; secondly, to ascertain a development process of Packages of Practice (PoP) of crops based on the identified parameters through a mobile-based information system; and thirdly, to analyse user satisfaction of the PoP knowledge and justify the app as a decision support system.

MATERIALS AND METHODS

Design methodology for innovative artefact

The research methodology called Design Science Research (DSR) was used for the study; it is a powerful research paradigm to create an innovative artefact for the real-world (human) problem as a direct valid research output. The validity of artefacts is determined through strict theoretical grounding in an academic context and field testing (Devitt and Robbins 2013; Henver and Chatterjee 2010). It is a technique of gaining knowledge related to the situation by building and evaluating artefacts. This method can be applied to many fields, including ICT, engineering, architecture, and even education (Kuechler and Vaishnavi 2011). Thereby, creating new knowledge in previously un-researched areas and areas without earlier investigations or theoretical background reinforces the method. However, the completeness and effectiveness of artefacts depend on how satisfying the requirements are and solving the existing problem (Hevner *et al*. 2004; Kuechler and Vaishnavi 2011; Devitt and Robbins 2013).

Study areas, target groups and crops

The research study was carried out in major crop-growing areas in Sri Lanka, namely Badulla (Boralanda and Keppetipola), Nuwara Eliya (Seetha Eliya and Blackpool), Jaffna (Puthoor and Urumburai), and Monaragala (Udawalawa) districts. Farmers and home gardeners were selected for the study to deploy the artefacts. This target population was chosen mainly based on the opinions of subject matter experts, achieving different identified needs of those categories, and balancing the local demand for produce. As an initial establishment of the artefact for commercial and smallholder farmers, potato and brinjal were selected. In addition, 35 crops, including spices, fruits, leafy vegetables, herbs, root crops, traditional crops and a few other vegetables, were chosen as the first-round crops for home gardeners, based on the suggestions given by the subject experts.

Sample size and sampling technique

One hundred farmers, including commercial and smallholders, were selected using a purposive sampling technique for the initial study of potato production (Detail study discussed in Mohamed *et al*. 2021). In order to capture the socio-economic factors and context knowledge, farmers were mainly selected from major potato-growing districts in Sri Lanka; Badulla, Nuwara Eliya, and Jaffna. The Brinjal related information was collected from the Udawalawa area of the Monaragala district using a snowball sampling technique with 35 participants, including farmers, agriculture instructors, and subject knowledge experts. Common challenges faced by the farmers and home gardeners were gathered from a number of field visits made in the above-mentioned areas. Furthermore, 32 app users were randomly selected to analyse PoP knowledge satisfaction of the *Govi-Nena* Home Gardening app.

DSR cycles with actors

DSR consists of three cycles: Relevance, Rigor, and Design and those circulated through three main domains: Environment, Knowledge base, and Design Science (Hevner 2007). In our study, a set of components in the application domain was identified as agriculture experts, including farmers, agriculture instructors, and research officers. Further, the research results/developed artefacts/output must be returned into the environment for ultimate evaluation and study. The next set of components in the application domain, identified as mobile app users/farmers (Hevner

2007; Järvinen 2007). Hence, information was (requirements, problems, and opportunities) gathered from identified domain experts through a series of field visits. In rigor cycle, the study was examined several sources of knowledge from related institutions and existing artefacts to provide foundations for the artefacts (Iivari 2007). The modifications were incorporated to the artefacts in the design cycle based on repetitive itterative steps of artefact verification, validation and evaluation until a satisfactory artefact is achieved.

Data collection, verification, validation and implementation of artefacts

Crop production has been mainly dependent on the farming life cycle and can classify into five major stages: crop (variety) selection, pre-planting, growing, harvesting and post-harvesting (Figure 2: Section 1). Our research can be categorised into three sections according to the research objectives. The first part of the study was developing a crop selection model based on the agro-ecological regions (AER) in Sri Lanka using the DSR approach. Primary data were collected through several field visits conducted in the areas mentioned above by formal and informal discussions with subject knowledge experts. Secondary data were mainly collected from the Natural Resource Management Center- Department of Agriculture. To provide contextual data, verified this model through agriculture domain experts (research officers and agriculture instructors) from Agrarian Service Centers of the Department of Agriculture – Welimada (Badulla), Horticultural Crop Research and Development Institute (HORDI) - Gannoruwa, and Fruit Research and Development Centre - Horana. It was then validated and redesigned the model based on the discussions held with agriculture domain experts. Providing recommended crops and their varieties based upon the AER was the utmost efficient way for farmers to make a better decision during the crop/variety selection stage. An AER covers whole environmental conditions in a particular location. The revised classification indicated 46 AERs (Figure 2: Section 2) currently available in Sri Lanka (Punyawardena *et al.* 2003; Chithranayana and Punyawardena 2008). The classification factors presented in Senanayake *et al.* (2017), including cultivation seasons, irrigation types, and land elevation, were considered in our research study and enhanced the crop selection model by compiling updated context data and information (Figure 2: Section 3). The crop selection model has initially classified based on the major cultivation seasons as *Yala* and *Maha*. In addition to these two seasons, incorporated a category of Perennial to represent perennial crops. Then, *Yala* and *Maha* divided into Rainfed and Irrigated based on the irrigation types and further sub-divided based on land elevation, Upland and Lowland. An AER has nine separate crop lists based on the different combinations, and the model shows different crop lists for 46 AERs in Sri Lanka (Figure 2: Section 4). Generally, a crop has one or more varieties, but not all of them can be cultivated in every location. Each variety is usually specific to one or a few AERs or farm locations. Hence, the study was further extended to AER-based variety selection. A separate workbook was prepared for selected crops of commercial and home garden cultivations (Figure 2: Section 5 for commercial cultivation of potato).

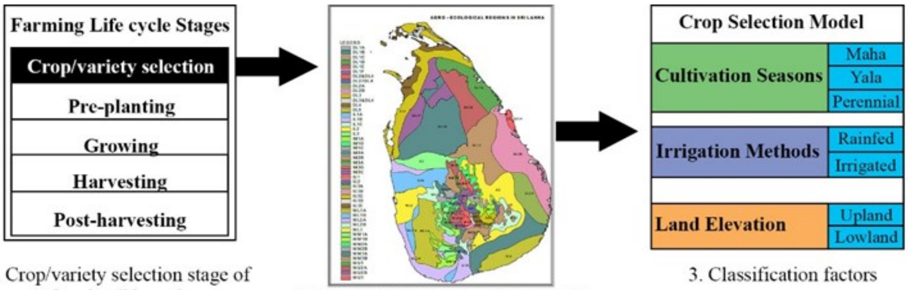
A second model, called Packages of Practice (PoP), was developed to support the crop selection model. These models were workbooks/ spreadsheets containing context-specific and actionable information that assist farmers during each step of the farming life cycle of crop production. However, PoP served as a guideline or design criteria for the activities in the farming life cycle, which developed based on the different factors/ conditions/ parameters/ constraints that influence farmers' decisions. The related study briefly discussed by Mohamed *et al.* (2020) indicates that the farming life cycle has expanded into different sub-stages with various factors/ conditions. These aspects help farmers make critical decisions at each farming life cycle stage, allocate available resources efficiently, assist in following necessary steps in the PoP about balancing the environmental quality and plant health and achieving satisfactory yield. However, the sub-stages and factors in the farming life cycle will be modified based on the updated information/knowledge captured from the farmer context due to evolving new technologies and innovations over time, government policy changes, availability of resources and farmer preferences. Hence, unknown factors under each farming life cycle stage should be incorporated. Primary (several interviews using pre-tested structured questionnaires) and secondary (books, leaflets, websites and other publications from relevant institutions, research articles, meta-artefacts (existing agriculture-based mobile apps)) sources were used to develop PoP workbooks. The developed PoP was then verified through interviews and discussions held with agriculture domain experts (experienced farmers, agriculture instructors, and research officers). The PoP model was validated and redesigned based on the need assessment of domain experts via several face-to-face discussions and group discussions. Finally, the PoP was refined based on the comments and feedback provided by the domain experts. Additionally, a Google form-based questionnaire was distributed among users of the Govi-Nena Home Gardening App to analyse the PoP knowledge satisfaction. Responses were collected using the 5-point Likert scale method and analysed using the Wilcoxon one sample signed-rank test.

The existing ontological crop knowledge base was used to store the PoP workbooks (Walisadeera 2014; Walisadeera *et al.* 2015). It acts as a repository and provides the domain knowledge in a structured format (Gruber 1995). Based on the refined PoP, the existing ontology was enhanced with domain knowledge. The stored PoP workbooks were represented through a mobile-based information system named "*Govi-Nena*" ("Farmers' Intelligence"). There were two versions of the *Govi-Nena* mobile apps (http://www.govinena.lk/) : "*Govi-Nena* Farmer" app is for farmers and the "*Govi-Nena* Home Gardening" is for home gardeners. However, the designed PoP model will be modified based on updated knowledge/information and the farmer's context.

RESULTS AND DISCUSSION

The designed model for crop and variety selection has been implemented through the *Govi-Nena* mobile-based platforms. Farmers/users can easily find recommended crops and varieties suitable to their farms by adding their intended location for growing crops. To do this, users can create farms using the *My Crops* icon in the *Home* menu (Figure 2: Section 6). To get the recommended crop and its varieties in the *Govi-Nena* Farmer app, users need to provide details such as *Farm Name, Farm Extent (whether acre or hectare), Extent Unit, Province, District, District Secretariat (DS) division, Grama Niladari (GN) division, and Soil pH.* Optional fields to create a farm include Carbon%, Phosphorus%, Potassium%, Nitrogen%, and Water sources were optional fields to create a farm (Figure 2: Section 7). Users can create any number of farms in any location in Sri Lanka (Figure 2: Section 8). After creating farm/s, that will be stored in the *My Crops* icon as a list representing farm names. Accordingly, users can easily find the recommended crops and varieties with their images suitable for the selected locations (Figure 2: Section 9). However, in the *Govi-Nena* Home Gardening App, the crop and variety recommendations are provided mainly based on agro-climatic zones (ACZs) instead of AERs in Sri Lanka. This is because home gardeners prefer to cultivate many crops in a small area of land, and providing recommendations based on ACZ covers a broad range of crops that can be grown in a location.

Figure 3 shows how the mobile interfaces depict the representation of the packages of practice (PoP) artefact through mobile apps and the information flow of the PoP for selected crops and varieties in particular farms. Sections 1-4 of Figure 3 represent the potato PoP of the *Govi-Nena* Farmer app, while sections 5-8 represent the PoP of selected crop varieties in the *Govi-Nena* Home Gardening app. The PoP instructions or activities are shown separately by dates, reflecting the actionable format of the information. These instructions will pop up in the app as notifications to the users based on time (Figure 3: Sections 2 and 6). However, the PoP guidelines were recorded in the growing activity calendar (Figure 3: see Sections 4 and 8), which supports users in knowing the PoP activities briefly and provides direct access to



1. Crop/variety selection stage of farming life cycle

Source: Land use policy planning division, Aug 2005

2. Agro-ecological regions in Sri Lanka

3. Classification factors

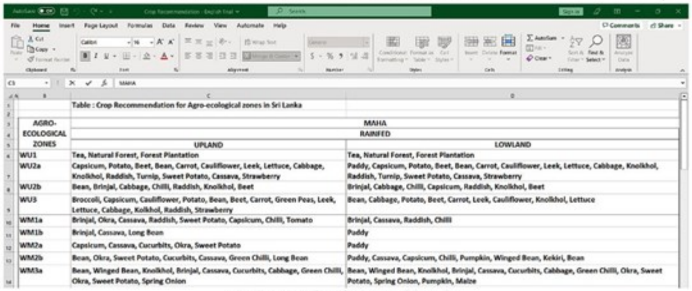
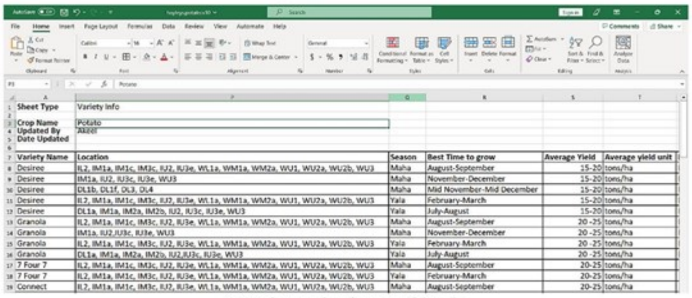


Table : Crop Recommendation for Agro-ecological zones in Sri Lanka

AGRO-ECOLOGICAL ZONES	MAHA	
	RAINFED	
	UPLAND	LOWLAND
WU1	Tea, Natural Forest, Forest Plantation	Tea, Natural Forest, Forest Plantation
WU2a	Capsicum, Potato, Beet, Bean, Carrot, Cauliflower, Leek, Lettuce, Cabbage, Knolkhol, Raddish, Turnip, Sweet Potato, Cassava, Strawberry	Paddy, Capsicum, Potato, Beet, Bean, Carrot, Cauliflower, Leek, Lettuce, Cabbage, Knolkhol, Raddish, Turnip, Sweet Potato, Cassava, Strawberry
WU2b	Bean, Brinjal, Cabbage, Chilli, Raddish, Knolkhol, Beet	Brinjal, Cabbage, Chilli, Capsicum, Raddish, Knolkhol, Beet
WU3	Broccoli, Capsicum, Cauliflower, Potato, Bean, Beet, Carrot, Green Peas, Leek, Lettuce, Cabbage, Kolkhol, Raddish, Strawberry	Bean, Cabbage, Potato, Beet, Carrot, Leek, Cauliflower, Knolkhol, Lettuce
WM1a	Brinjal, Okra, Cassava, Raddish, Sweet Potato, Capsicum, Chilli, Tomato	Brinjal, Cassava, Raddish, Chilli
WM1b	Brinjal, Cassava, Long Bean	Paddy
WM2a	Capsicum, Cassava, Cucurbits, Okra, Sweet Potato	Paddy
WM2b	Bean, Okra, Sweet Potato, Cucurbits, Cassava, Green Chilli, Long Bean	Paddy, Cassava, Capsicum, Chilli, Pumpkin, Winged Bean, Kekiri, Bean
WM3a	Bean, Winged Bean, Knolkhol, Brinjal, Cassava, Cucurbits, Cabbage, Green Chilli, Okra, Sweet Potato, Spring Onion	Bean, Winged Bean, Knolkhol, Brinjal, Cassava, Cucurbits, Cabbage, Green Chilli, Okra, Sweet Potato, Spring Onion, Pumpkin, Maize

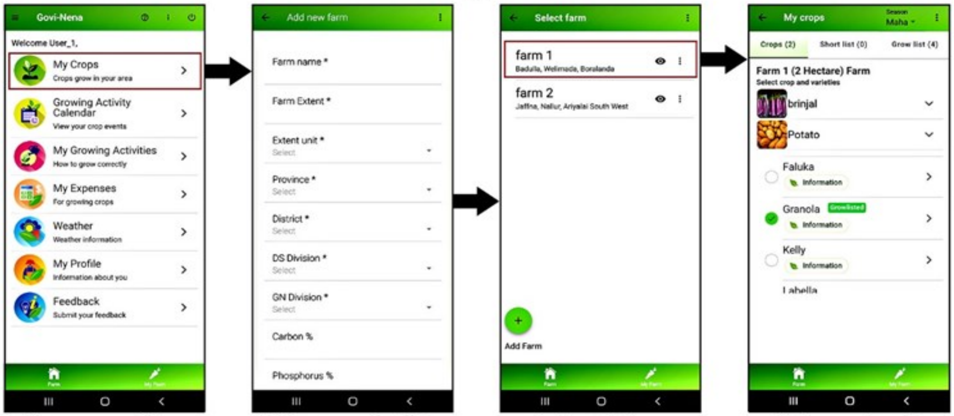
4. Crop selection workbook



Sheet Type	Variety Info
Crop Name	Potato
Updated By	Akeel
Date Updated	

Variety Name	Location	Season	Best Time to grow	Average Yield	Average yield unit
Desiree	IL2, IM1a, IM1c, IM3c, IU2, IU3e, WL1a, WM1a, WM2a, WU1, WU2a, WU2b, WU3	Maha	August-September	15-20	tons/ha
Desiree	IM1a, IU2, IU3c, IU3e, WU3	Maha	November-December	15-20	tons/ha
Desiree	DL1b, DL1f, DL3, DL4	Maha	Mid November-Mid December	15-20	tons/ha
Desiree	IL2, IM1a, IM1c, IM3c, IU2, IU3e, WL1a, WM1a, WM2a, WU1, WU2a, WU2b, WU3	Yala	February-March	15-20	tons/ha
Desiree	DL1a, IM1a, IM2a, IM2b, IU2, IU3c, IU3e, WU3	Yala	July-August	15-20	tons/ha
Granola	IL2, IM1a, IM1c, IM3c, IU2, IU3e, WL1a, WM1a, WM2a, WU1, WU2a, WU2b, WU3	Maha	August-September	20 -25	tons/ha
Granola	IM1a, IU2,IU3c, IU3e, WU3	Maha	November-December	20 -25	tons/ha
Granola	IL2, IM1a, IM1c, IM3c, IU2, IU3e, WL1a, WM1a, WM2a, WU1, WU2a, WU2b, WU3	Yala	February-March	20 -25	tons/ha
Granola	DL1a, IM1a, IM2a, IM2b, IU2,IU3c, IU3e, WU3	Yala	July-August	20 -25	tons/ha
7 Four 7	IL2, IM1a, IM1c, IM3c, IU2, IU3e, WL1a, WM1a, WM2a, WU1, WU2a, WU2b, WU3	Maha	August-September	20-25	tons/ha
7 Four 7	IL2, IM1a, IM1c, IM3c, IU2, IU3e, WL1a, WM1a, WM2a, WU1, WU2a, WU2b, WU3	Yala	February-March	20-25	tons/ha
Connect	IL2, IM1a, IM1c, IM3c, IU2, IU3e, WL1a, WM1a, WM2a, WU1, WU2a, WU2b, WU3	Maha	August-September	20-25	tons/ha

5. Variety selection workbook



6. Home menu of Farmer app

7. Necessary details to create a farm

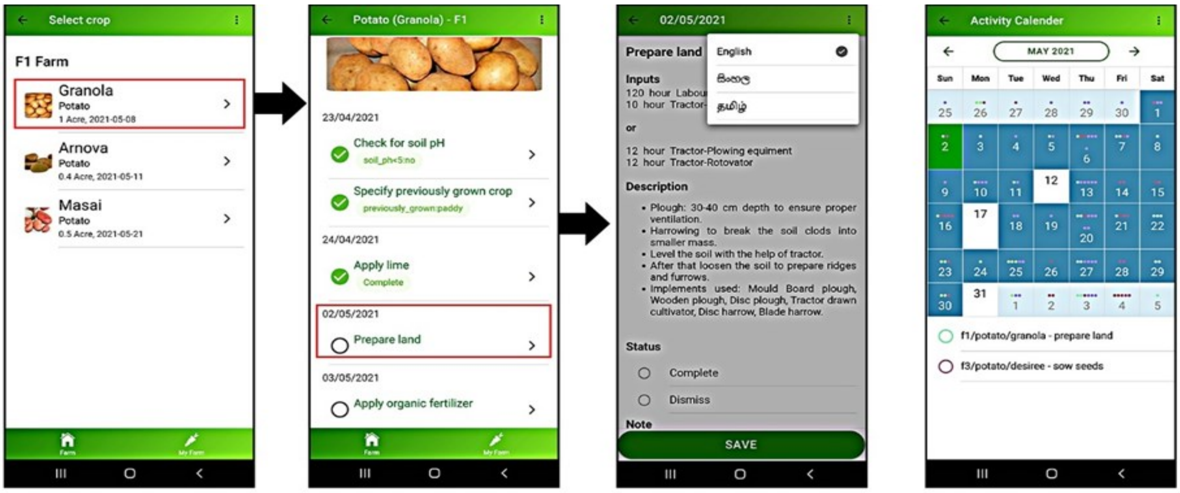
8. Created farms

9. Crop and variety selection

Figure 2: Crop variety selection model based on the agro-ecological regions of Sri Lanka was incorporated in the *Govi-Nena* Farmer App. (1) Five stages of the farming life cycle, (2) Revised classification of AERs (46) in Sri Lanka, (3) Major classification factors and sub-factors in the crop selection model, (4) A crop selection workbook with recommended crops for nine classification factor combinations (*Maha*-Rainfed-Upland, *Maha*-Rainfed-Lowland, *Maha*-Irrigated-Upland, *Maha*-Irrigated-Lowland, *Yala*-Rainfed-Upland, *Yala*-Rainfed-Lowland, *Yala*-Irrigated-Upland, *Yala*-Irrigated-Lowland (6) Home menu of *Govi-Nena* Farmer App, (7) Necessary details which users need to provide to create a farm, (8) Farms created by users, (9) Recommended crops and their varieties suitable for growing location

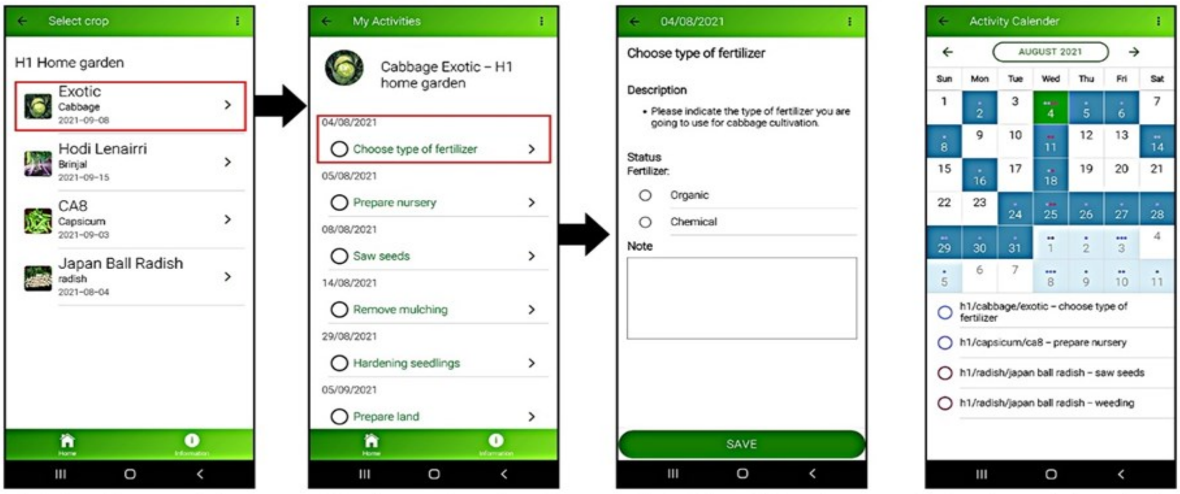
the specific action of detail PoP. Further, this calendar shows farm and crop-specific information in different colours to support users in identify and differentiate the farm and crop-specific practices. The detailed descriptions and input information (if available) of two selected PoP activities are displayed in Sections 3 and 7 of Figure 3. Similarly, each activity in the PoP has a space for users to add comments, indicated as "Note" on the Screens. This space was provided to collect the updated/relevant information and any changes or issues if available with the information. In addition, Section 3 of Figure 3 shows the availability of accessing associated timely context information in three languages (English, Sinhala, and Tamil). Providing information in different languages is a highly convenient feature for those with language difficulties. They can quickly act in their own language of understanding the instructions provided through the apps. Otherwise, only a few farmers or users can understand one language completely (Sharma *et al.* 2018).

The proposed apps have been developed for Android and iOS platforms, and the Govi-Nena Home Gardening app is currently available on Google Play Store and Apple App Store. The Govi-Nena Farmer app has been



- Plough: 30-40 cm depth to ensure proper ventilation.
- Harrowing to break the soil clods into smaller mass.
- Level the soil with the help of tractor.
- After that loosen the soil to prepare ridges and furrows.
- Implements used: Mould Board plough, Wooden plough, Disc plough, Tractor drawn cultivator, Disc harrow, Blade harrow.

1. Selected potato varieties in the F1 farm
2. Packages of practice of Granola potato variety
3. Detailed activity of land preparation
4. Growing activity calendar of the Farmer app



- Please indicate the type of fertilizer you are going to use for cabbage cultivation.

5. Selected crop varieties in the H1 home garden
6. Packages of practice of exotic cabbage variety
7. Activity of choosing the fertilizer type
8. Growing activity calendar of the Home gardenning app

Figure 3: Information flow of obtaining planned activities in the packages of practice (PoP) of *Govi-Nena* Farmer app (Sections 1-4) and *Govi-Nena* Home Gardening App (Sections 5-8)

specially designed to assist conventional farming. The *Govi-Nena* Home Gardening app has been designed for organic and conventional farming to enrich quality production and increase ecosystem services through an organic approach.

The artefact evaluation process helps to test the completeness and usefulness of the designed artefacts. Socio-economic factors and knowledge satisfaction of the designed PoP in the *Govi-Nena* Home Gardening app were analysed with 32 app users. The majority in the sample were from the Southern (41%), Central (16%) and Eastern (16%) provinces and worked in the government (25%), academic (25%), other (25%) and agriculture (19%) sectors. A higher response rate was received from the male (69%) gender, the age category of 26-45 (75%), and no respondents identified an age above 66 years. Among the surveyed users, most have completed or are pursuing a university education (75%).

To analyse the PoP knowledge satisfaction, different statements were developed for each segment of the knowledge provided in the app (Table 1). The results revealed that, at a 95% confidence level, the P-value for all statements is less than 0.05. Therefore, the null hypothesis is rejected. So, the difference between the sample median and the hypothesised median is statistically significant and the satisfaction level of all statements in the sample is higher than the hypothesised median (3). According to the results, statements numbers 4, 12, 5, 3, 17, 1, 6, 9, 15, 8, 13, 10, 16, 2, and 14 show higher satisfaction levels compared to other statements.

All provided guidelines, including input rate and time, strictly follow the recommendations given by reliable sources and incorporate artefacts that have already been verified and validated by a group of agriculture experts. Hence, artefacts enabled mobile apps to provide necessary instructions on successfully growing crops by considering the farming life cycle. However, the developed artifacts have been further enhanced based on farmer/user preferences and requirements during various stages of the iterative process (Figure 4: Sections 1-4).

Additionally, the home gardening app has a separate module of helpful information consisting of common guidelines for home gardening, information on natural and biological pest control methods, guidelines to make composts, and liquid organic fertilizer. In order to enhance ecosystem services for some levels, instructions were incorporated in the home gardening app such as instead of using synthetic pesticides, looking of natural pest and disease control methods to safeguard crops, providing details of different types of organic fertilizers to increase soil structure, fertility and biodiversity, encouraging intercropping and crop rotation to balance the impact of biotic aspects, increasing manual weeding to avoid chemical weeding methods, and some other eco-friendly practices. Practices related to organic production can highly motivate home gardeners when compared to large-scale farming concerning labour force and time. Even though kitchen wastes, animal and fish manure and other freely available organic wastes can be used to produce some useful input sources or directly apply those in the fields to fulfil nutrient needs of home garden crops. However, organic farming or transitioning to organic from the conventional system may not provide immediate satisfactory yields during the initial establishment period due to the slow release of required nutrients (Garbach *et al.* 2017). Nevertheless, developing favourable ecosystem services both above and below ground through a long-term approach will sustain crop yield, minimise environmental degradation and reduce the usage of external inputs.

Most of the currently available features and functions have been incorporated into the PoP and apps based on comments and feedback given by the domain experts through validation and refinement cycles. Such updates are as follow: location-specific PoP, user preference-based PoP, colour-coded crop calendar to manage planned activities better, a feedback module to understand the farmer context and improve information flow among farmers and knowledge providers, an expense calcula-

Table 1: Analysis of knowledge satisfaction on *Govi-Nena* Home Gardening PoP activities

Statements	Z value	P value	Decision
1. Agro-climatic region-based crop/ variety selection	3.636	0.000*	Reject the null hypothesis
2. Amount of information provided	2.610	0.009*	Reject the null hypothesis
3. Quality of information provided	3.785	0.000*	Reject the null hypothesis
4. Accuracy of information provided	4.221	0.000*	Reject the null hypothesis
5. Choosing fertilizer types (organic/ in-organic)	4.110	0.000*	Reject the null hypothesis
6. Choosing organic fertilizer types (poultry manure/compost/cow manure)	3.625	0.000*	Reject the null hypothesis
7. Information regarding the liquid organic fertilizer preparation and application procedure	2.147	0.032*	Reject the null hypothesis
8. Information regarding the nursery preparation methods of some special crops (Eg: Brinjal, Tomato, Capsicum, Green chili, Cabbage)	3.534	0.000*	Reject the null hypothesis
9. Information regarding land preparation and basal fertilizer application	3.604	0.000*	Reject the null hypothesis
10. Sowing seeds/ establish suckers or stem cuttings	3.053	0.002*	Reject the null hypothesis
11. Information regarding transplanting (for Brinjal, Tomato, Capsicum, Green chili, Cabbage)	2.012	0.044*	Reject the null hypothesis
12. Apply top dressing (Urea, TSP and MOP)	4.170	0.000*	Reject the null hypothesis
13. Information regarding weeding practices	3.305	0.001*	Reject the null hypothesis
14. Information regarding fix trellises and vine training (for Bitter gourd, Winged bean, Bitter gourd, Cucumber, Luffa, Pumpkin, Yard long bean)	2.559	0.010*	Reject the null hypothesis
15. Information regarding harvesting	3.539	0.000*	Reject the null hypothesis
16. User friendliness of the provided information	2.805	0.005*	Reject the null hypothesis
17. Overall satisfaction about information/knowledge	3.716	0.000*	Reject the null hypothesis

*Significance level =0.05

tor in the Farmer app to predict the cost of cultivation in the basis of the farming life cycle, farms and crop varieties, and a weather module to provide real-time weather information in users' area, along with a summary report of weather and forecast for the next five days. The earlier version of the app did not contain enough information and features

(Figure 4: Section 1). The location-specific PoP means that growing activity changes may be happened based on soil and locational characteristics. For example, the application rate of fertilizer changes with different districts in cabbage cultivation, and the application rate of lime changes based on soil pH and previously grown crops in potato cultivation. The user preference-based PoP describes that the farmers/users can select any options based on the preferences given in the PoP, and the remaining activities in the PoP will rearrange based on the selection made by the farmers accordingly. However, users have hands-on control to change their choices at any time if they feel they made an incorrect selection. Some practices include selecting storage methods, specifying previously grown crops, choosing fungicides to control blight disease in potato PoP, and controlling pest or disease attacks in potato and the brinjal PoP. Most of the home garden vegetable PoP have options to cultivate crops, whether organically or conventionally and choose organic fertilizer types

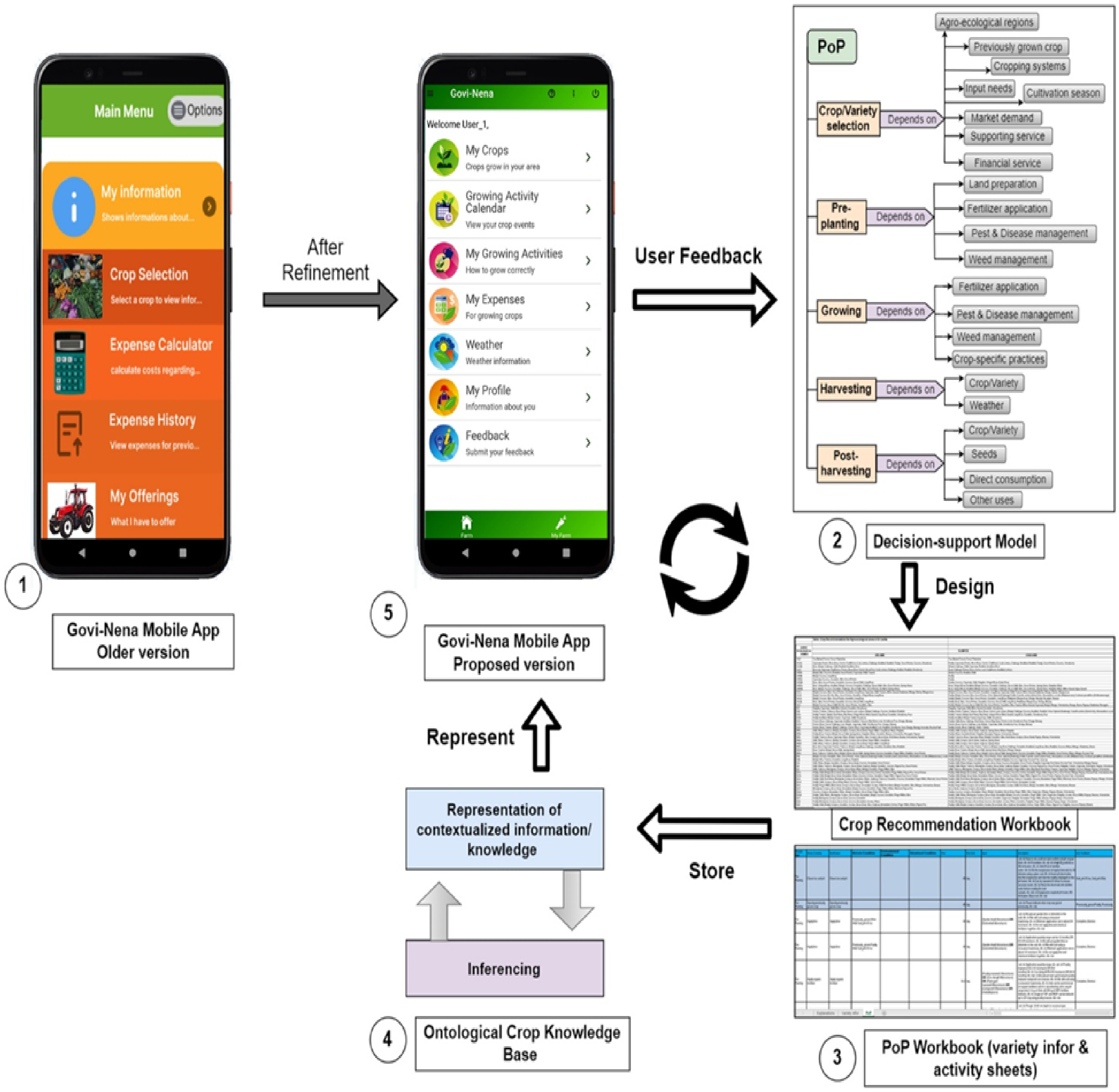


Figure 4: Proposed decision support system

in the PoP. Further, implementing the feedback system is crucial for the agriculture sector to trace farmer context. It will help minimise waste and crop losses and save time through quick interventions facilitated by information flow (Soysa 2008). The way forward, these mobile apps (Figure 4: Sections 5) act as a decision support system that empowers farmers and gardeners to make timely quality decisions for their routine farming activities to improve yields, reduce excess cost and save time.

CONCLUSIONS

Food insecurity and insufficient produce have had a significant impact on the population of the emerging world in recent years. In the agriculture domain, farmers are the most important stakeholders, and they need to make crucial decisions at certain stages of the farming life cycle to improve crop production. Key challenges identified in the study highlight the fact that farmers and home gardeners require context-specific, complete, actionable information to make timely and quality decisions for successful crop production. This paper provides a roadmap for gaining insights into avoiding useless decisions and efficiently managing time and input resources in the farming process by adopting the best packages of practice (PoP).

Crop selection is the primary stage that sets the model to provide recommended crops and their varieties associated with the AER in Sri Lanka. This model has been incorporated into the PoP workbooks, which are enabled by the growing activity calendar. The discussed artefacts were represented through the mobile-based information systems, notably the "*Govi-Nena* Farmer" and "*Govi-Nena* Home Gardening", to support conventional and organic methods of cultivation. The user evaluation study of the Home Gardening app shows that the higher number of users in the Southern province (41% of all respondents) may be due to several awareness workshops conducted in those areas. This indicates that conducting promotional and marketing activities encourages people to learn more about the app and its features, which supports its widespread use among a large audience. The majority of respondents in the surveyed sample have a good educational background, with about 75% of users having completed or currently following degree programs. The results further revealed that the young generation is more likely to use this innovative technology to manage their daily cultivation activities. Additionally, most of the Home Garden app users in the sample work in non-agricultural sectors, as they are not experienced farmers and lack sufficient knowledge in farming. Major interruptions in the food supply system caused by the COVID outbreak encouraged households to cultivate crops for their consumption. Furthermore, the user satisfaction analysis of PoP knowledge reveals that all users in the sample are pleased ($p<0.05$) with the information provided in the app. Statements on information accuracy ($Z = 4.221$), fertilizer application ($Z = 4.170$), fertilizer type selection ($Z = 4.110$), and information quality ($Z = 3.785$) represent a higher level of satisfaction.

Therefore, providing timely necessary information/ knowledge for better decision-making using a user-friendly mobile app will be an effective way to increase yield and ecosystem services while minimising the cost of production by reducing expenses. This digital approach to decision-making will undoubtedly add value to enhance agricultural sustainability in Sri Lanka. Some probabilities are improving soil fertility and quality, minimising environmental risks due to an increase of ecosystem services and proper handling of farm inputs, ensuring food security due to minimising yield gap and secure crop yields, reducing poverty due to increasing harvests, improving the livelihood of farmers as a result of establishing the digital extension system and lowering the cost of production.

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AUTHOR CONTRIBUTION

MSAM, DLW and WAI conceptualised and designed the study. MSAM conducted the survey and analysed and interpreted the data. MSAM drafted the manuscript. All authors discussed the results and commented on the manuscript.

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