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# Temporal Variation of Phytophagous Insects of *Calotropis gigantea* (L.) in Southern Province of Sri Lanka

[*1]Wijeweera WPSN, [1]de Silva MPKSK, [2]Dhileepan K & [2]Senaratne KADW

[1] *Department of Zoology, University of Ruhuna, Matara, Sri Lanka*

[2] *Biosecurity Queensland, Department of Agriculture and Fisheries, Ecosciences Sciences Precinct, Dutton Park, Queensland, Australia*

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**[*]Corresponding Author**

*Email: surendi87nisha@gmil.com*

**ABSTRACT**

*Calotropis gigantea* is a native plant to Sri Lanka having an ayurvedic medicinal value. People use the plant to gain fodder, fiber, and fertilizer. Despite its benefits, the plant is considered as an invasive species in Australia, the USA, etc. As the plant is medicinally, agriculturally, and ecologically valuable, the study was designed to investigate phytophagous insects of *C. gigantea* and their temporal variation. The field visits were conducted fortnightly from August 2015 to August 2016 in eleven sites in Southern Province (SP). During sampling, the number of insect species, their abundance, and the number of *Calotropis* fruits were recorded in selected trees. Twenty-nine insect species were recorded from *C. gigantea* and among them twelve species were phytophagous. *Dacus persicus* and *Paramecops farinosa* were destructive phytophagous insects. *D. persicus* was recorded in all three districts of SP throughout the year and the mean abundance varies significantly (p= 0.002) among districts. *P. farinosa* was only recorded from Hambantota district. *Sphaeroderma* sp. was the most abundant phytophagous insect and varied widely across (p = 0.000) districts of Southern Province. *Danaus chrysippus* larva was observed in all selected sites of SP. None of the insect abundance correlated with *Calotropis* fruit density, month of year and monthly rainfall.

## 1. Introduction

The behavior and biology f insect species that live in different parts of the world vary as a response to biotic and abiotic factors and are reflected as temporal variation [1]. Temporal variation is a function of time [2] and it shows the insect response (abundance/ behavior) over a period of time. The temporal variation of tropical insects is more complicated and less studied [3]. They show temporal variation as a response to rainfall and other biotic and abiotic parameters. As a result, insects in tropical regions show significant temporal variation with respect to the local climate, altitude, phenology of the host plants, etc. [3].

*Calotropis* spp. are tropical plants that are home to numerous insects. These insects are generally classified as pollinators [4], pests [5], occasional visitors, and predators [6]. According to a study from Saudi Arabia [7], insects associated with *Calotropis procera* are classified as pests, neutral insects, scavengers, parasitoids, floral visitors, and predators. Among them, pests play a major role as they feed on plant parts.

Insect pests and their damage to *Calotropis* spp. are well documented [8]. When considering the information on insect fauna associated with *Calotropis* spp., most of the records are from India while very few records are available in Sri Lanka. Few species of bees including *Amegilla comberi*, *Amegilla fallax, Amegilla violacea*, *Xylocopa fenestrate* and *Xylocopa tenuiscapa* were reported as pollinators of *Calotropis gigantea* in Sri Lanka [9]. In addition, Butterfly larvae of *Danaus chrysippus chrysippus* were recorded as feeders on *Calotropis* leaves and flowers [10,11].

However, temporal variation of insects associated with *Calotropis* spp. are less studied in the entire world except for a few studies from India. In India, insect pests associated with *Calotropis* spp. were recorded throughout the year. The highest

abundance of insect pests has been recorded during the summer season and the least abundance has been recorded in the winter season [5].

All parts of the *C. gigantea* plant are used in Ayurveda medicine of Sri Lanka. It is used for treating blood clotting, wound healing, bronchitis, dysentery, inflammation, asthma, snake bite, and scorpion poisoning [12-15]. In addition, Sri Lankan farmers use latex of the plant for sticky traps. Alpha and Beta calotropeol and Beta amyrin in latex act as an excellent chemical mixture to use in pest control of crops [16]. Especially sugarcane farmers use plant latex to control termite attacks in crop fields [17]. Furthermore, under laboratory conditions, it has been proved that extraction of *C. gigantea* plants is effective in controlling cotton mealy bug [18]. Despite its benefits, *C. gigantea* is an emerging problem in the USA, Mexico, Australia, Caribbean Islands, etc. where the plant is considered as an invasive species [8]. As the plant has medicinal, agricultural and ecological value in Sri Lanka, it is important to study insects associated with the plant and their temporal variation as they have a close association with the production/reproductive output of the plant.

However, there are no recordings of the temporal variation of insects on the plant within Sri Lanka or any other part of the World. In addition, knowledge on temporal variation is essential for forecasting future changes in community structure and ecosystem function [3]. Thus, studies on temporal variation in communities remains an important and interesting challenge in ecology [3]. Therefore, this study was conducted with the objective of examining the temporal variation of phytophagous insects associated with *C. gigantea* plants in selected sites in the Southern Province of Sri Lanka.

## 2. Material and Methods

### Study sites

To study the temporal variations in phytophagous insects of *C. gigantea*, eleven sites from Southern province having easy access from University of Ruhuna (19) were selected (Table 1). The sites were selected randomly, and the sites were located more than 3 km from each other including both inland and coastal regions. Sites within hundred meters towards the seashore are considered as coastal sites while rest of the sites are considered as inland sites [19]. The study sites contained a minimum of six mature *C. gigantea* plants and all of them were approximately similar in size assuming similar size *C. gigantea* plants belong to the same age. The stems of the selected plants were numbered with white paint.

All the plants in each site were sampled at two weeks' time intervals from August 2015 to August 2016. Insects on selected *C. gigantea* plants were closely observed using a hand lens and photographed while spending approximately 3 hours in a site, allocating a minimum of 20-30 minutes per plant [20]. During sampling, the number of phytophagous insects on *C. gigantea*, the number of individuals of each phytophagous insect species landing on *C. gigantea,* their interactions with the plant and the number of fruits in each plant were recorded.

**Table 1: Details of study sites**

| District | Site | Location |
|---|---|---|
| Matara | Kamburugamuwa | $5^0$ 56' N; $80^0$ 29' E |
| | Devinuwara | 50 56' N; $80^0$ 34' E |
| | Palena | $5^0$ 56' N; $80^0$ 29' E |
| Galle | Dadalla | $6^0$ 02' N; $80^0$ 11' E |
| | Thalpe | $5^0$ 59' N; $80^0$ 16' E |
| | Habaraduwa | $5^0$ 59' N; $80^0$ 18' E |
| | Kathaluwa | $5^0$ 58' N; $80^0$ 20' E |
| Hambantota | Kalametiya | $6^0$ 06' N; $80^0$ 55' E |
| | Medilla | $6^0$ 02' N; $80^0$ 48' E |
| | Tangalle | $6^0$ 01' N; $80^0$ 47' E |
| | Nalagama | $6^0$ 04' N; $80^0$ 47' E |

### Preservation and identification of phytophagous insects

Live insect samples were collected using sweep nets into small vials. Insects were directly collected from various parts of the plant (leaves, flowers, stems, fruits) by hand nets. The specimens were transported to the University of Ruhuna and preserved, pinned at the laboratory of the Department of Zoology. Specimens were identified by taxonomic expertise of Entomologists of Entomology Division, The Horticultural Crop Research and Development Institute (HORDI), Gannoruwa, Sri Lanka. Unidentified specimens were sent to taxonomists in Australia and India for identification.

### Statistical analysis

Monthly rainfall data related to Southern Province (during sampling period) were obtained from Sri Lanka Meteorological Department (http://www.meteo.gov.lk). Statistical analysis was done using environmental data by developing correlations with the mean abundance of selected insect species. The one-way analysis of variance (ANOVA) is used to determine whether there are any statistically significant differences between the mean abundance of selected phytophagous insects among sites of three districts of Southern Province. The statistical analysis was done using Minitab 16 Statistical Software [20].

 

## 3. Results and discussion

**Table 2: Phytophagous insects associated with *Calotropis gigantea* in Southern Province**

| Order | Family | Scientific name |
|---|---|---|
| Coleoptera | Chrysomelidae | *Sphaeroderma* sp. |
| | Curculionidae | *Paramecops farinosa* Schoenherr |
| | Cerambycidae | *Phelipara moringae* Aurivillius |
| | | *Sybra praeusta* Pascoe |
| Hemiptera | Lygaeidae | *Graptostethus servus* Fabricius |
| | | *Spilostethus hospes* (Scopoli) |
| | | *Spilostethus pandurus* Militaris |
| | Cercopidae | *Abidma refula* |
| | Membracidae | *Leptocentrus* sp. |
| | Aphidae | *Aphis nerri* Boyer de |
| | | Fonscolombe |
| Diptera | Tephritidae | *Dacus persicus* Hendel |
| Lepidoptera | Papilionidae | *Danaus chrysippus* L.. |

Twenty-nine insect species were observed on *C. gigantea* during the study. Among them, twelve species of phytophagous insects belonging to nine families were recorded (Table 2). *Sphaeroderma* sp.; was the most common (67.50%) insect pest associated with *C. gigantea* in the Southern province of Sri Lanka. *Paramecops farinosa* and *Dacus persicus* were identified as highly destructive monophagous insects [8]. They feed on 100% seeds while destroying the whole fruit and directly influence the reproductive output of the plant [8,19, 20,21].

Out of twelve phytophagous insects, six species namely *D. persicus*, *P. farinosa*, *Sphaeroderma* sp., *Spilostethus* sp., *A. nerri* and *D. chrysippus* larvae were abundant and act as major or moderately damaging pests which directly influence on reproductive output/growth of the plant. Other species were uncommon, and they cause negligeable/minor damage to the plant. Therefore, temporal variation was only studied on above phytophagous insects. Monthly variation of mean abundance of them in three districts of Sothern province are given in Figures 1, 2, 3, 4, 5 and 6.

### Comparative study of phytophagous insects across districts of Southern province

*Dacus persicus* was recorded in all three districts of Southern province. However, there was a significant difference in the mean abundances of *D. persicus* ($p = 0.002$, $F = 7.4$) at least in two districts. Comparatively higher abundance of *D. persicus* was recorded in Galle district (12.18± 4.11) while lower abundance was in Hambantota district (0.60± 0.30) (Figure 1).

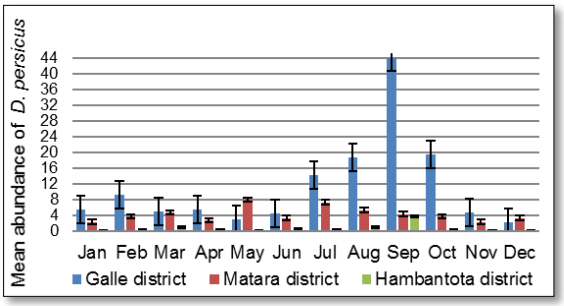


**Figure 1: Monthly variation of mean abundance of *D. persicus* in districts of Southern Province (bars represent standard deviation).**

Female *D. persicus* is attracted to *Calotropis* fruits for oviposition. Male *D. persicus* were common on *Calotropis* fruits to get a chance for mating. Therefore, we studied whether the abundance of *D. persicus* link with *Calotropis* fruit abundance. However, statistically, there was no correlation ($r = 0.252$, $p = 0.139$) between them. Similarly, the monthly rainfall of the Southern province had no influence ($r = -0.237$, $p = 0.164$) on *D. persicus* abundance.

*P. farinosa* was recorded only from the Hambantota district (Figure 2).

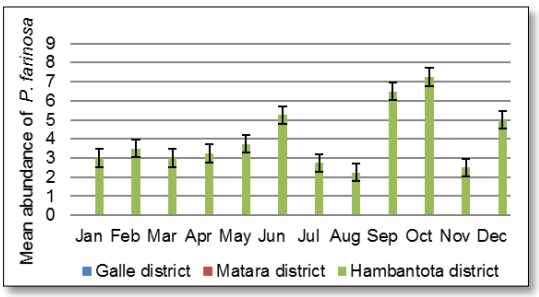


**Figure 2: Monthly variation of mean abundance of *P. farinosa* in districts of Southern Province (Bars represent standard deviation).**

Graphically, there were fluctuations in mean abundance of P. farinosa (Figure 2). In India, [23], *P. farinosa* is active throughout the year but is least abundant during the winter season (December to February). As there is no winter season in Sri Lanka, similar observations were not recorded. Even though *P. farinosa* oviposit in *Calotropis* fruits, no correlation was obtained ($r = -0.268$, $p = 0.115$) between the mean abundance of *Calotropis* fruits and the mean abundance of *P. farinosa*. Similarly, their abundance was not correlated with rainfall.

*Sphaeroderma* sp. was observed throughout the Southern province and their abundance also significantly varied (p = 0.000, F= 15.68) among districts. However, their mean abundances not significantly change according to time (month) as well as monthly rainfall.

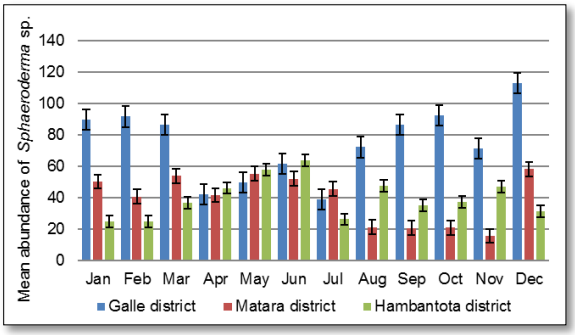


**Figure 3: Monthly variation of mean abundance of Sphaeroderma sp. in districts of Southern Province (Bars represent standard deviation)**

*Spilostethus* spp. were collected in all districts of Southern province throughout the year and similar observation was recorded from India as well [5]. Their abundance was comparatively higher in June and July (Figure 4). Even though, there was no correlation (r = 0.437, p = 0.008) between *Calotropis* fruit abundance and abundance of *Spilostethus* spp., field observations revealed that, a large number of nymphs and adults associated with ruptured/ mature fruits as they feed on seed sap. According to studies in India, *Spilostethus* sp. abundance was highly correlated with the environmental factors while the maximum temperature act as a limiting factor of population [5]. Similarly, in India, higher abundance of their population was observed from September to May with the onset of rain [5].

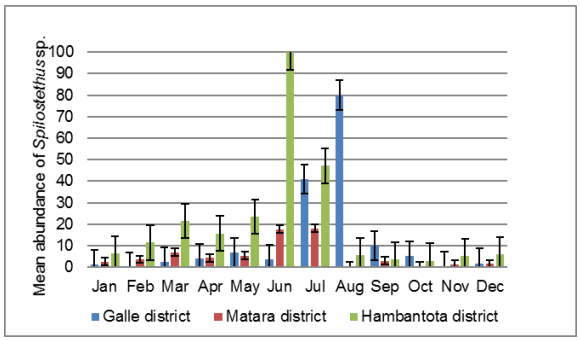


**Figure 4: Monthly variation of mean abundance of *Spilostethus* spp. in districts of Southern Province (bars represent standard deviation)**

Peak aphid infestation (mean-15.33) was recorded during January in Hambantota as well as during October (mean- 18.13) in Matara district. The lowest abundance of the aphid was recorded during August in three districts of Southern Province (Figure 5). However, no significant difference in the mean abundances of aphid colonies at least in two districts during 12 months of study period (p= 0.191, F= 1.74) indicating no notable mean differences in abundances of aphid colonies among districts.

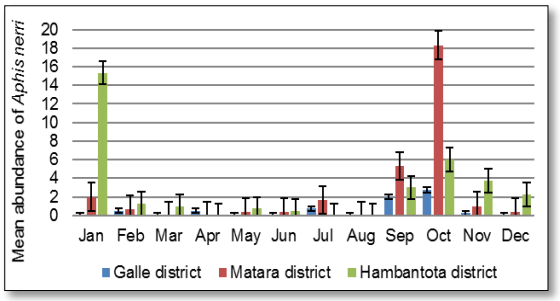


**Figure 5: Monthly variation of mean abundance of *Aphis nerri* colonies in districts of Southern Province (bars represent standard deviation).**

Comparatively higher mean abundance of *Danaus chrysippus* larvae was recorded in Hambantota (1.542± 0.39) and Matara district (0.859 ± 0.28) than in Galle (0.416± 0.09) district (Figure 6) which are less urbanized districts.

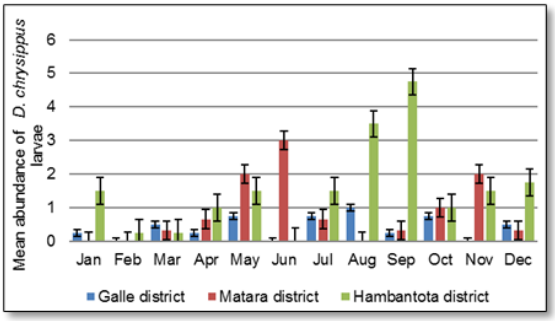


**Figure 6: Monthly variation of mean abundance of *Danaus chrysippus* larvae in districts of Southern Province (bars represent standard deviation).**

**Monthly variation of phytophagous insects across the sites of Galle, Matara and Hambantota**

*D. persicus* was recorded in all sites except Kathaluwa (Galle district) and Devinuwara (Matara district). Dadalla was the only site, where *D. persicus* was recorded throughout the year with high abundance (Table 3). It might be due to resource availability around the sampling area. In Hambantota district, *D. persicus* was recorded in all sites. It might be due to climate suitability of the district for survival of *D. persicus*. According to the present study, *D. persicus* covered a wider range of distribution than *P. farinosa*. It might be due to vigorous flying ability of *D. persicus*. Similar observations were recorded from India also [20].

*P. farinosa* was recorded in the Hambantota district only. When compared to Matara and Galle, the Hambantota district was less urbanized. *P. farinosa* were highly sensitive to urbanization [22] and as a result, they might be restricted to the Hambantota; a district with more rural areas. Even in Hambantota district, *P. farinosa* was not found in the highly urbanized Tangalle site. The site was closer to the main road which was highly polluted by the smoke of vehicles and dust. The polluted and urbanized nature of the site might be the possible reason for the absence of *P. farinosa* in the Tangalle site. The lethargic, slow-moving nature of P*. farinosa* [8] and the patchy distribution of *C. gigantea* plants through the land also limit the distribution of *P. farinosa* [21, 23].

*Sphaeroderma* sp. was recorded in all sites and their abundances were fluctuating throughout the year. The remarkable abundance of *Spilostethus* sp. was also recorded in the Thalpe site (Table 2) and their highest abundance was observed during March, June, July, and August. *A. nerri* were recorded in all sites except Dadalla, Habaraduwa (Galle district) and Medilla (Matara district) sites. *Danaus chrysippus* larvae were recorded from all surveyed sites (Table 3).

**Table 3: Monthly variation of mean abundance (± S.D) of pests across the sites of Galle, Matara and Hambantota districts**

| District | Site | Mean insect abundance (± S.D) | | | | | |
|---|---|---|---|---|---|---|---|
| | | *D. chrysippus* larvae | *Aphis nerri* | *Spilostethus* spp. | *Sphaeroderma* sp. | *P. farinosa* | *D. persicus* |
| Matara | Devinuwara | 0.05± 0.2 | 0.45± 1.6 | 0.37± 1.1 | 4.88± 5.6 | 0.00± 0.0 | 0.00± 0.0 |
| | Kamburugamuwa | 0.14± 0.5 | 0.17± 0.8 | 0.20± 0.8 | 4.50± 5.0 | 0.00± 0.0 | 0.86± 1.3 |
| | Palena | 0.15± 0.5 | 1.18± 8.3 | 1.71± 4.7 | 7.62± 9.8 | 0.00± 0.0 | 0.85± 1.8 |
| Hambantota | Kalametiya | 0.21±0.6 | 0.77± 4.1 | 5.70± 23.5 | 7.25± 6.9 | 0.80± 1.3 | 0.02± 0.1 |
| | Medilla | 0.05± 0.2 | 0.00±0.0 | 1.72± 3.4 | 7.20±10.3 | 1.30± 1.8 | 0.23± 1.0 |
| | Nalagama | 0.17± 0.9 | 0.62± 2.2 | 0.36± 1.2 | 1.24± 2.5 | 0.66±1.9 | 0.02± 0.2 |
| | Tangalle | 0.47± 1.3 | 0.32± 1.4 | 6.86±23.2 | 10.82±11.1 | 0.00± 0.0 | 0.10± 0.5 |
| Galle | Thalpe | 0.03±0.2 | 0.05±0.3 | 10.9±34.8 | 21.89±18.4 | 0.00± 0.0 | 1.40 ±4.5 |
| | Habaraduwa | 0.08 ±0.3 | 0.00± 0.0 | 0.21 ±0.8 | 5.77 ± 4.9 | 0.00± 0.0 | 0.16±0.7 |
| | Kathaluwa | 0.04±0.2 | 0.23±0.8 | 0.22 ±0.7 | 6.02 ± 6.9 | 0.00± 0.0 | 0.00± 0.0 |
| | Dadalla | 0.06±0.3 | 0.00±0.0 | 0.14±0.5 | 14.91±12.7 | 0.00± 0.0 | 6.06± 8.5 |

## 4. Conclusion

Twelve insects associated with *C. gigantea* was identified as phytophagous insects. Among them, *D. persicus* and *P. farinosa* were prominent phytophagous insects. Mean abundances of *D. persicus* varied significantly (p= 0.002) among districts. Similar observation (p= 0.000) was recorded for the most abundant insect pest; *Sphaeroderma* sp. *P. farinosa* was only recorded from Hambantota district of the southern province. However, the abundance of all studied pests was not varied according to the *Calotropis* fruits density, month of the year and monthly rainfall.

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# Teachers' Perceptions on their In-Service Professional Development Opportunities in Sri Lanka

Senevirathna Bandara

*Department of Humanities, Faculty of Social Sciences and Humanities, Rajarata University of Sri Lanka, Mihintale, Sri Lanka*

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***Corresponding Author**
*Email:senevi@ssh.rjt.ac.lk*

**ABSTRACT**

Teacher Professional Development (TPD) is a very important part in education system of the country. Because the education system need well developed, skillful, potential teachers to make valuable people for the future society. Therefore teachers need high quality Teacher Professional Development opportunities over there professional life. Unfortunately some developing countries unable to organize and provide such like Teacher Professional Development (TPD) programs overtime. This study attempted to investigate teachers' perceptions on their Teacher Professional Development (TPD) opportunities and make suggestion to plan, organize and implement sustainable TPD programs in Sri Lanka. Case study method was used in study and data were collected by interviews. Findings of the study revealed in Sri Lankan education system not established proper in-service TPD policies as a result teachers are not provide sufficient TPD opportunities.

## 1. Introduction

Professional development is defined as the process within which members of organizations are given the encouragement, resources and rewards necessary to develop their intellect and professional skills on a continuing basis, Evans & Nation [1]. For the Teacher Professional Development concept, many different terms are used by researchers and others involved in educational practices. Some of these are: teacher professional development; teacher professional learning, continuing teacher education, continuing professional development, ongoing career development, in-service teacher education, in-service teacher learning, in-service teacher training Lalitha [2]. Further, Villegas-Reimers [3] mentioned as; nowadays, most reforms of education that are designed and implemented include a main component of teacher professional development as one of the key elements of the changing process in education. Thus teachers' roles have become complicated and broader in scope. Greenwood & Gaunt [4] compares a teacher of a class to a chief executive, needing both to understand the 'business' throughout and the socio-political environment in which it operates, and to be able to help people (the students) to carry out their work effectively. Further, they have to work with children not only collectively, perhaps when explaining a goal or delivering information, but also individually, making judgments about how best to help each student on the basis of their subject knowledge and their knowledge of a students' needs. Under such a situation, teachers should be given the opportunities to update their knowledge, skills and attitudes, because we are in a new era of teaching which is increasingly complex and demanding Fullan [5], Hargreaves [6].

Therefore, well designed, thoughtfully planned and adequately supported professional development is an essential component and an ingredient in the process of teacher professional development, Good JM. Weaver & Andrew [7].

The impact of classroom practice is depicted in the Figure 1. This figure shows the connections of effective professional teacher education in improving teacher quality which lead to changing classroom teaching practice. The final outcome is the improvement in student learning.

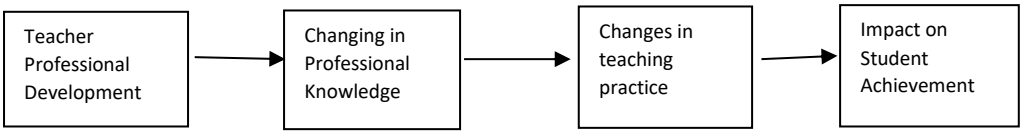


**Figure 1: Teacher PD and impact on students' outcomes** :Source [8]

Educators and policymakers are increasingly looking to teacher professional learning as an important strategy for supporting the complex skills students need to be prepared for further education and work in the 21st century. Effective professional development (PD) is key to teachers learning and refining the pedagogies required teaching these skills Darling-Hammond [9].

However, Jenning, [10] observes that externally organized professional development programs may be employed in a 'top to bottom' approach, depicting the traditional and hierarchical order, and they therefore do not have a significant impact on teachers. This can happen because the external professional development providers are not closely in touch with the needs of the individual teachers and the particular schools.

### 1.1. Teacher professional development in Sri Lanka

Ministry of Education (MOE) [11] states that Sri Lanka has already considered professional development for teachers as an essential part of the education system because professional development enhances the quality of good teaching. Further, Hayman [12] pointed out that well organized professional development programs can enhance teachers' skills, knowledge and attitudes. Whereas, The Ministry of Education (MOE) of Sri Lanka has recognized, that "good teachers are keys to enhance the quality of education and therefore need to be providing avenues of professional advancement" [11 p. 22]. Furthermore, the MOE [11] report shows that; Sri Lanka has already realized teacher professional development as an obvious part of the education system in the country.

However, Sri Lankan teachers have only a few opportunities to participate in professional development activities in a year, Lalitha [2]. Furthermore, the opportunities for teachers to participate to this professional development programs depend on their teaching subject; for example, teachers who teach core subjects have more opportunities than teachers teaching other subjects (the core subjects in secondary schools are Mathematics, Science, Languages (Sinhalese, Tamil and English), and Social-Studies).

It is necessary then that the national policy makers in Sri Lankan education make relevant policies to develop a wider range of TPD opportunities. This study explores the effective strategies which will require enhancing current TPD programs in secondary schools, and it is anticipated that these findings will help to make national policies to develop effective and efficient TPD opportunities in the future. The findings and recommendations of the study will also be useful for planning, organizing and providing suitable professional development programs to school teachers by the MOE or National Institute of Education (NIE).

Furthermore, there is potential for these teacher professional development programs to be developed to improve the professional standards and required interpersonal and other skills of school teachers; nonetheless the development of these programs is one of the many complicated issues within the education system in Sri Lanka. Therefore, this research inspired to investigate the current situation of TPD programs and teachers' perceptions on Teacher Development opportunities in ten selected secondary schools in two different Provinces in Sri Lanka

## 2. Research methodology

For this study, qualitative research approach has been employed and the research design was framed within an interpretive and case study research method. In this research, a case study method is believed to be appropriate because this study needs to investigate teacher perceptions on TPD programs in ten Government schools. Further, Anderson [13, p. 121] defines case study as "a specific phenomenon within its real-life context". In addition, Neill [14] also says that case study focuses on investigating the phenomena of a single case in-depth. Thus Purposive sampling method was used to select ten schools within Kandy and Nuwaraeliya administrative districts in Central Province accordingly researcher's convenience. In this investigation twenty teachers were randomly chosen from above mentioned ten schools. Furthermore, the data collection process employed in-depth interviews which were conducted with twenty school teachers who were chosen from a sample of ten Government schools.

**Table 1: Sample of schools and teachers**

| Type of schools | Number of schools | Number of teachers |
|---|---|---|
| National | 3 | 6 |
| 1 AB | 1 | 2 |
| 1 C | 6 | 12 |
| Total | 10 | 20 |

### 2.1 Objectives of the study

- To explore different types of TPD programs which provide to teachers in education system of Sri Lanka
- To examine the effective methods of TPD programs in the education system

- To evaluate teachers need and demand of their TPD
- To assess teachers suggestions to develop quality of TPD programs in the country

### 2.2 Limitations of the study

For this study ten schools were selected and 20 teachers of the schools were interviewed, therefore these findings should not to be generalized to all government teachers in the country. Further, only qualitative data was collected for this study.

## 3. Results and Discussion

Data were collected by interview and the collected qualitative data has been categorised into four codes (themes) as listed below.

1. Advantages and disadvantages of current TPD programs.
2. Teachers needs of TPD opportunities
3. Types and methods of TPD programs in Sri Lanka
4. Teachers suggestions for developments of TPD programs

Data were categorized and analysed manually by the Researcher.

### 3.1 Findings of the study

The findings show Sri Lankan teachers have less opportunities to develop their Professional development. Under such a situation TPD programs are ineffective and insufficient, as a result these TPD programs not support to develop students' outcomes. Among the sample 19 teachers (The majority of the teachers) mentioned that Sri Lankan education system do not have clear guidance and government policies, relevant to TPD programs and encouragement.

Hence, 80% participant of the selected sample believed that the TPD opportunities are not enough for teachers. Some participants were mentioned some teachers are not provided at least one TPD program per year, even some opportunities are defend on the subject, educational zones, subject directors of the education and allocation for the TPD programs. All teachers of the sample accepted the importance of TPD programs for teacher development, but they firmly criticized the current TPD programs in Sri Lanka. A participant said that, "at the end of the every year, in the December before finishing allocated money many TPD programs are organized by the Zonal Education Office (ZEO) and these are Ad-hock and ineffective opportunities'.

The present TPD programs are mainly organized and conducted by the Zonal Education Office (ZEO), although ZEO was strongly criticized by the participated teachers. Some of the criticisms were made by the teachers and these are mentioned below, 5% participants complained about TPD programs, as these TPD programs are mostly used to introduce changes to the syllabuses, national reforms and subjects' knowledge for teachers. There is a limited opportunity for professional development. The next important reason is that unqualified human resources are used to conduct TPD programs; mainly these programs are organized by the ZEO and they do not have the expertise. Even the provincial offices do not have qualified resources to plan, organize and implement these programs. In addition teachers highlighted some disadvantages of TPD programs in Sri Lanka as; TPD programs did not consider teachers' and schools' individual needs, some TPD programs were organized at national level and held in the capital city of the country, which required teachers to travel long distances. In addition, different types of teachers gathered at the same center for TPD seminars or workshops, resulting in a loss of enthusiasm during the period of program.

## 4. Conclusion

The study investigated teachers' perceptions on their in-service TPD opportunities, in qualitative research approach, case study method is used to the research. Data were collected by applying individual interviews; according to the study all teachers of the sample believed that, their TPD programs are insufficient and less effective. Further Sri Lankan education system not formulated national policy and guidance for TPD programs, further in these TPD programs unqualified human resources were used by organizers. Some programs were held quite far from the teachers' working schools therefore they have to travel long distance to participate to TPD programs. Finally to enhance TPD programs in Sri Lanka the participant teachers made some suggestions for organizers of TPD programs in the education system.

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# Use/non-use of *ne* in Spoken French by L2 and L3 French Speakers

Gunawardena Chandeera

*Department of Modern Languages, University of Kelaniya, Dalugama, Sri Lanka*

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***Corresponding Author**
*Email: chandeera@kln.ac.lk*

**ABSTRACT**

The present paper examines the acquisition of sociolinguistic competence by proficiency-matched third language (L3) and second language (L2) French speakers whose first language (L1) is either English or Sinhala. The ability to change the register of the target language appropriately according to different social contexts is the most important aspect of sociolinguistic competence that L2/L3 learners need to acquire. However, previous studies show that non-native speakers often find it difficult to use sociolinguistically appropriate language even after many years of learning an additional language in formal settings. Further, previous L2 studies have focused on corpora derived mainly from immersion students who speak European languages. Therefore, there have been, to date, virtually no variationist studies on the use of French sociolinguistic variables by L1-Sinhala-L2-English-L3-French learners. The present study intends to fill the gap in research by investigating knowledge of verbal negation in the French-Sinhala interlanguage. The originality of the present study lies in the research design. It compares data derived from proficiency-matched L2 and L3 French speakers. The results suggest that the L2 group can use socially appropriate speech more effectively than the L3 group.

## 1. Introduction

This study investigates how adult first language (L1) Sinhala speakers acquire verbal negation in third language (L3) French. The present study contributes to the growing research strand in the field of second language (L2) acquisition studies that focuses on sociolinguistic competence by L2 and L3 learners. Previous L2 studies have focused on corpora derived mainly from immersion students who speak European languages [1,2,3,4,5,6,7]. Furthermore, there have been, to date, virtually no variationist studies on the use of French sociolinguistic variables by L1-Sinhala-L2-English-L3-French learners [1,3,4,7]. Therefore, the present study intends to fill the gap in research by investigating knowledge of verbal negation in the French-Sinhala interlanguage.

The ability to change the register of the target language appropriately according to different social contexts is the most important aspect of sociolinguistic competence that L2 learners need to acquire [2]. However, it is generally observed that non-native speakers often find it difficult to use sociolinguistically appropriate language even after many years of learning an additional language in formal settings [8].

L2 acquisition studies mainly focus on the acquisition of invariant morphosyntactic structures [6,7]. However, this study was conducted within the framework of L2 variationist sociolinguistics. Labov [10] introduced the variationist approach to the study of languages (L1s), and the main assumption of this approach is that variations in language use are not random but highly systematic. Further, L1 variationist studies maintain that native speakers' choice between variants is constrained by social factors [9,10]. Turning to variationist L2 studies, they investigate whether non-native speakers can use socially appropriate and acceptable speech in the target language [6]. Further, they try to ascertain whether patterns of interlanguage variations are similar to the variations observed in native speech [10, 2].

Dewaele [6] maintains that instructed L2 learners seem 'reticent about using informal variants. Further, he found that non-native French speakers prefer to use formal variants in informal contexts. Turning to another debate in L2 acquisition, Blanche-Benveniste [11] argues that L2 grammars remain permanently non-native-like, whereas other scholars argue that the acquisition of subtle grammatical properties can be acquired [7,12,13,14]. Therefore, the present study will also provide evidence regarding the debate, which concerns the question of whether L2/l3

learners could acquire subtle grammatical properties in the target language.

According to Dewaele [6], the ability to use socially appropriate language in French is mainly determined by the ability to delete *ne* (the first particle of verbal negation in French). Therefore, the present study focuses on verbal negation as a way of ascertaining sociolinguistic competence of L3 French speakers whose L1 is Sinhala. Further, the originality of the present study lies in the research design. It compares data derived from proficiency-matched L2 and L3 French speakers whose L1 is either English or Sinhala.

Turning to the syntax of verbal negation, in contemporary written French, the verbal negation comprises two elements: the preverbal particle *ne* and the postverbal negator *pas* 'not' as in (1) [6]. In addition to the postverbal negator 'pas', French uses other postverbal negators like *plus* 'no longer, *rien* 'nothing', jamais 'never'. In spoken French, the native speakers often delete the preverbal particle *ne* as in (2).

1. Il ne parle pas
   He NEG talk not.
   'He does not talk.'

2. Il parle pas
   He talk not.
   'He does not talk.'

The organisation of the paper is as follows. First, I briefly review previous studies on verbal negation. Research objectives and predictions precede the research design, which is followed by a discussion in which I discuss the results in light of the predictions.

## 2. Review of literature

### 2.1. Omission of *ne* in L1 French

The behaviour of native speakers in relation to sociolinguistic variables has been the focus of many studies [13,14,15]. According to Coveney [10], the negative particle *ne* is 'the best-known sociolinguistic variable in French'. Coveney [10] looked at the retention and deletion of *ne* in Picardy French, and he found an average omission rate of 81.2 percent. Further, he noted that young informants from lower socio-economic classes omitted *ne* more frequently.

Moreau [3] analysed a corpus derived from radio speech where the retention rate was only 50.2%, whereas Armstrong [16] examined a corpus of adolescent's speech from Lorraine and found that the *ne* retention rate is significantly low (2.9%). Diller [17] also reports similar results. He investigates the retention and deletion of *ne* by twelve rural speakers in southern France, and he found a 65.5% *ne* retention rate. Hansen and Malderez [18] investigated the verbal negation in Parisian French and found the retention rate is only 18%.

Turning to the other verities of French, Fonseca-Greber [19] analysed a corpus from Switzerland and found a significantly low retention rate of *ne* (2.5%). However, their sample size was relatively small (n=14). Sanfoff and Vincent [20] examined verbal negation in Canadian French. They analysed the speech of sixty L1 French speakers from Montreal and found that the *ne* retention rate was close to zero.

### 2.2. Omission of *ne* in non-native French

Trevise and Noyau [1] conducted one of the seminal studies on the omission of *ne* in L2 French. They collected data from L2 French speakers with Spanish as an L1. They interviewed the participants (n=8) in two situations. First, they used an elicited production task to collect data, whereas, in the second instance, the participants were asked to listen to the recording and comment on their own production. The authors expected the participants to use the informal variant in the first recording. However, in the second recording, they expected the participants to use a formal register. They found that their registers do not differ in the two recordings. Interestingly, their data showed inter-individual variations linked to the participants' linguistic history in French. They maintain that the length of stay in a francophone country, age, and frequency of use of French are linked to the *ne* omission rate.

Rehner and Mougeon [21] looked at the *ne* omission rate of forty English-speaking Canadian pupils. They also found a positive correlation between the frequencies of *ne* non-use in students' speech and their exposure to native spoken French both outside and within the school context. They also found that the pupils who worked with native French teachers demonstrated a higher *ne* omission rate than those who worked with non-native French teachers (20% versus 32%). However, as expected, the overall results showed that L2 learners deleted *ne* less frequently (28%) than native speakers.

Regan [5] studied a corpus gathered through sociolinguistic interviews. Her participants were L1 Irish English speakers. She interviewed participants before and after participating in a study abroad programme. Although she found inter-individual variations, the overall results suggest that the participants omitted *ne* considerably more after their stay abroad (65 versus 38%).

Interestingly, Sax [7] also reports similar results by analysing a corpus gathered through interviewing Anglo-American students (*n*=35). The results indicated that learners who had not spent time in a francophone country had an average retention rate of 93 %. In contrast, those who have spent time abroad recorded an average omission rate of 75%.

Dewaele [6] examined a corpus produced by a large sample size (*n*=73). The corpus consists of both

 

native and non-native speakers. The participants were enrolled in the BA French program at Birkbeck College, University, and they were pre-advanced, L2 French speakers. As expected by the author, he found that native speakers deleted *ne* more frequently than the non-native speakers. The findings showed no positive correlation between the omission of *ne* and gender. The results also suggest that the non-native speakers' linguistic history (frequency of use of French) strongly influences the *ne* omission rate.

The researchers have also discussed the relationship between L2 learners' knowledge of sociolinguistic competence and classroom instructions [22,23,24]. L2 studies show that learners encounter difficulties acquiring target sociolinguistic features through implicit classroom instructions. Therefore, scholars recommend introducing target sociolinguistic features through explicit instructions [24].

## 3. Hypotheses

Based on the findings of previous research related to studies of *ne* use by non-native speakers of French, I formulated the following hypotheses.

### 3.1 Hypothesis 1

The native speakers will have a higher *ne* omission rate than the non-native speakers.

### 3.2 Hypothesis 2

Frequent users of French will have higher omission rates of ne.

### 3.3 Hypothesis 3

L1-Sinhala-L2-English-L3-French speakers and L1-English-L2-French speakers will have similar omission rates.

## 4. Methodology

### 4.1 Participants

Forty-five participants took part in the study. There were two non-native groups and a native group. The first non-native group included sixteen L3 French speakers (female: 14; age mode: 22; range: 21-25), and their prior languages were Sinhala and English. The second non-native group had seventeen L2 French speakers (female: 15; age mode: 19; range: 18-25) whose prior language was English. The native group included twelve L1-French speakers (female: 09; age mode: 22; range: 21-25).

The L2 French speakers were recruited from the University of York, UK, whereas the L3 speakers were recruited from Sri Lanka. All non-native speakers were enrolled in French classes as part of a French-language degree. The L1 French speakers were visiting students from France enrolled in undergraduate degree programmes at the University of York. A language and socio biographical questionnaire was administered to all the participants. The L2 group confirmed that they speak French as an L2, whereas the L3 group indicated that they speak French as a foreign language (L3). Ten participants in the L3 group reported that they rarely use French outside the classroom. However, the number of participants who use French rarely in the L2 group was relatively small (see Table 2). The data collected via a questionnaire (see Tables 1 and 2).

**Table 1: Summary of participants background questionnaire**

| Group | Age | | Gender |
|---|---|---|---|
| | Mode | Range | Male |
| L3 Speakers *(n=16)* | 22 | 21-25 | 02 |
| L2 Speakers *(n=17)* | 19 | 18-25 | 02 |
| L1 Speakers *(n=12)* | 22 | 21-25 | 03 |

**Table 2: Active use of French outside the classroom**

| Frequency | Number of participants | |
|---|---|---|
| | L3 speakers | L2 speakers |
| Rarely | 10 | 5 |
| Occasionally | 4 | 4 |
| Frequently | 2 | 8 |

The non-native speakers completed a validated cloze test in French, developed by Zac and Garrison [25]. The authors report that the main purpose of creating the cloze test was to create a "valid, reliable and practical tool which helps researchers to discriminate between L2 French learners from a wide range of proficiency levels'' (p. 84). The cloze test had been validated by recruiting French learners from the University of Illinois. The test involves filling in forty-five missing words in a text. For the base text, the authors selected a non-academic article selected from *le Monde* (Newspaper). The missing words included 23 content words (nouns, adjectives, verbs, etc.) and 22 function words (determiners, prepositions, pronouns, etc.). The results of the proficiency test are reported in Table 3.

The independent samples t-test showed that the L2 speakers (*M=16.60, SE=2,41*) and L3 speakers *(M=14.38, SE=2.75)* are not significantly different with respect to the French language proficiency ($t(31)= -1.87$, $p> .05$). Further, the results confirm that the non-native speakers are intermediate speakers of French.

**Table 3: Proficiency test scores**

| | Minimum | Maximum | Test mean score (SD) |
|---|---|---|---|
| L2 Speakers (*N=17*) | 10 | 23 | 16.60 (2.41) |
| L3 Speakers (*N=16*) | 08 | 22 | 14.38 (2.75) |

***French proficiency scores (out of 45)**

### 4.2 Corpus

The corpus is based on one-to-one audio-recorded conversations (between the participants and researcher). It is believed that an informal speech style can best be obtained in spontaneous speech [2,6,10]. Therefore, the researcher asked questions related to the informants' immediate environment (family, friends, university life, and motivation to study French, weather, holidays, reading books, watching movies). The researcher obtained ethics approval from the University of York, UK. To adhere to the accepted ethical standards, the researcher avoided sensitive topics like death, politics, health and religion. The conversations were 30 to 40 minutes long. The conversations were recorded using a voice recorder. Following the Labovian variationist approach, the researcher transcribed only the occurrences of the variable that he intended to analyze.

The participants were briefed about the objectives of the study, and informed consent was obtained. The anonymity of the participants was ensured through the use of codes, and confidentiality was safeguarded. The participants were informed that they could withdraw from the study at any point. The following section reports the results of the present study.

## 5. Results

The native and non-native speakers used 634 verbal negations. Further, I identified 243 cases of omission of *ne* and 391 cases of retention (see Table 4). The results show that the native speakers preferred the omission of *ne* over its retention (52.31% versus 47.68%). This shows that the results of the native speakers are compatible with previous results reported in previous studies.

Turning to the non-native speakers, unlike the native speakers, they preferred the retention of *ne* over its omission. Interestingly, the L3 speakers looked very different from the other two groups. Their retention rate of *ne* is over 80%, and the omission rate is less than 20%. The L2 speakers omitted *ne* more frequently than their L3 counterparts (29.41% versus 19.53%).

**Table 4: *Ne* use and non-use by native and non-native speakers.**

| Group | Verbal negations (n) | Use of ne (n) | Non-use of *ne* (n) | Use of *ne* (%) | Non-use of ne (%) |
|---|---|---|---|---|---|
| **L3 Speakers (*n=16*)** | 128 | 103 | 25 | 80.47 | 9.53 |
| **L2 Speakers (*n=17*)** | 204 | 144 | 60 | 70.59 | 9.41 |
| **L1 Speakers (*n=12*)** | 302 | 144 | 158 | 47.69 | 2.31 |

Turning to the inferential statistics, Following Dewaele [26], I run a two-sample K-S test to determine whether there is a significant difference in the non-use of ne between the L2 speakers and L3 speakers (see Table 5). Thus, Field [27] also recommends K-S test as it has a better power than the Mann-Whitney test when samples are less than about twenty-five per group. The result was statistically significant (K-S Z =1.80, p = < .05). Therefore, the results suggest that the two non-native groups differ from each other with respect to the use of particle *ne*.

**Table 5: Non-use of *ne* between L2 speakers and L3 speakers.**

| | | |
|---|---|---|
| Most Extreme Differences | Absolute | .629 |
| | Positive | .000 |
| | Negative | -.629 |
| Kolmogorov-Smirnov Z | | 1.805 |
| Asymp. Sig. (2-tailed) | | .003 |
| Exact Sig. (2-tailed) | | .000 |
| Point Probability | | .000 |

Let us now consider *ne* use and non-use in relation frequency of speaking French language outside the classroom. The non-native speakers who use French rarely outside the classroom clearly showed a strong preference for the retention of *ne* (see Table 6). The non-native speakers who used French either occasionally or frequently omitted *ne* more frequently than those who speak the target language rarely (10.54 versus 15.06). The data presented in Table 5 are further illustrated in Figure 1. Thus, Table 6 clearly shows that the participants who used French rarely outside the classroom look very different from those who use it occasionally or frequently.

A two-sample K-S was run to determine whether there is a significant difference in the non-use of *ne* between frequent and rare users of French (See Table 7). Again, the result was statistically significant

((K-S Z =2.33, p = < .05). Therefore, the results suggest that frequent use of French is clearly linked to an increased deletion of *ne*.

**Table 6: Frequencies of *ne* use and non-use by non-native speakers**

| Frequency of speaking | Use of *ne* (n) | Non-use of *ne* (n) | Use of *ne* (%) | Non-use of ne (%) |
|---|---|---|---|---|
| **Rarely** | 150 | 35 | 45.18 | 10.54 |
| **Occasionally or frequently** | 97 | 50 | 29.21 | 15.07 |

**Figure 1: *Ne* use and non-use in relation to frequency of speaking French**

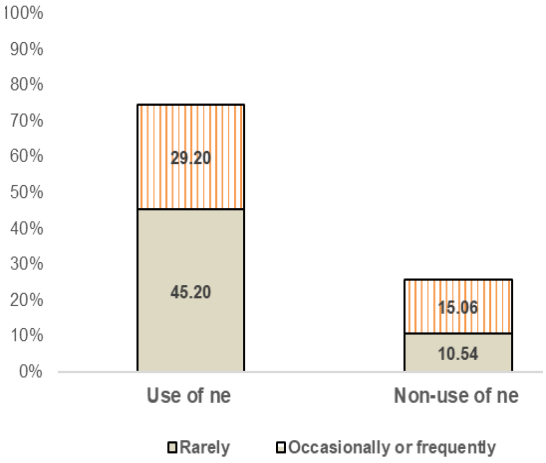


**Table 7. Non-use of *ne* between frequent and rare users of French**

| | | |
|---|---|---|
| Most Extreme Differences | Absolute | .864 |
| | Positive | |
| | Negative | .000 |
| Kolmogorov-Smirnov Z | | 2.339 |
| Asymp. Sig. (2-tailed) | | .000 |
| Exact Sig. (2-tailed) | | .000 |
| Point Probability | | .000 |

## 6. Discussion

This section discusses the results detailed in the previous section in light of the hypotheses. Three hypotheses were formulated based on previous studies on the acquisition of sociolinguistic competence by non-native French speakers. First, I recall these hypotheses and then examine them in relation to the results before concluding which hypotheses support the results.

Hypothesis 1 maintains that the native speakers will have a higher *ne* omission rate than the non-native speakers. Hypothesis 1 is borne out by the results by low rates of *ne* non-use (52.31%) in the native group. Further, the non-native speakers differ greatly with respect to the *ne* non-use (19.53% and 29.41%).

Turning now to Hypothesis 2, it claims that frequent users of French will have higher omission rates of *ne*. The results show that non-native speakers who frequently used French had a high omission rate of *ne* (15.07%). In contrast to Frequent French speakers, those who speak the language rarely showed a relatively low *ne* omission rate (10.54%). Further, A two-sample K-S result shows that the two groups significantly differ from each other. Therefore, Hypothesis 2 is supported by the results.

Hypothesis 3 maintains that L3 French speakers and L2 French speakers will have similar omission rates. The L3 group showed a strong preference for the use of the preverbal particle (80.47%), whereas the L2 group used the preverbal particle less frequently (70.59%). A two-sample K-S result shows that the two groups significantly differ from each other.

The results suggest that the L2 group can use socially appropriate speech more effectively than the L2 group. Why do the two non-native groups differ with respect to the *ne* omission rate? One possible variable that could influence their choice would be their knowledge of grammar. As mentioned previously, the two non-native groups do not differ with respect to French language proficiency. Therefore, we can conclude that knowledge of grammar could not be an important variable.

The other variable worth considering is the frequency of language use (outside the classroom) by the two groups. Table 6 shows that the L2 speakers use French more frequently than the L3 speakers. Therefore, lack of exposure to the target language could have influenced the L3 speakers to retain the *ne* particle more frequently in their speech. Previous studies also show that the use of the target language outside the classroom helps L2 learners to develop sociolinguistic competence. Therefore, the present study provides further evidence to show that interaction and exposure outside the classroom are required to develop L2 sociolinguistic competence.

## 7. Conclusion

The present paper investigated the acquisition of sociolinguistic competence by proficiency-matched L3 and L2 French speakers whose L1 is either English or Sinhala. The negative particle *ne* has been identified as the best-known sociolinguistic variable in French [10,26]. Therefore, as a way of investigating the knowledge of L2 sociolinguistic competence, this study focuses on the use/non-use of *ne* in French. Further, Previous L2 studies on French sociolinguistic competence have focused on corpora derived mainly

from immersion students who speak European languages [1,2,3,4,5,6,7,28]. To the best of my knowledge, there have been, to date, virtually no variationist studies on the use of French sociolinguistic variables by L3-French learners whose L1 is Sinhala. Therefore, the present study aimed to fill the gap in research by investigating knowledge of verbal negation in the L3 French. The findings showed that the native/non-native status of the speakers was correlated with omission rates. The results also suggest that frequency of French use helps non-native speakers to acquire sociolinguistic competence in the target language.

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# Pro-factors Delaying Post-war Reconciliation in Sri Lanka

*Upuldeniya DMR, Pannilage U and Amarasinghe SW

*Faculty of Humanities and Social Sciences, University of Ruhuna, Matara, Sri Lanka*

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***Corresponding Author**
*Email:ranupul@gmail.com*

**ABSTRACT**

Although it has been reported that the civil war which was prevailed for nearly three decades in Sri Lanka is over, the scholarly studies in the field have highlighted that even after around 11 years, the post-war reconciliation process in Sri Lanka is still facing numerous challenges. This study was conducted to investigate the factors that contribute to the hindrance of the reconciliation process between Sinhala and Tamil ethnic communities in Sri Lanka. The study employed a mixed-method approach where both the qualitative and quantitative data were gathered and analyzed. The literature review of the study is directed to place the study on a theoretical foundation based on sustainable reconciliation. Primary data were collected from a sample of both Sinhala and Tamil ethnic communities that were directly affected by the civil war. The gathered data were triangulated by verifying from various sources including key informant interviews and records of events. Data analysis were done through the thematic method. Qualitative data were analyzed using explanatory and content analysis methods while the quantitative data were analyzed using simple statistical calculations such as means and percentages. The findings of the study highlighted that the ethnic reconciliation process in Sri Lanka is facing challenges mainly due to lack of understanding of each other, inadequacy of political will to sort out the issue and socio-cultural factors including psychological factors that have not been solved for a long time.

## 1. Introduction

The civil war between the Sri Lankan government and Liberation Tigers of Tamil Eelam (LTTE) was a major catastrophe that stood against the country's development with a history of nearly thirty years. The end of the war has set the stage for all Sri Lankans to play a greater role in building a long-lasting peace between Sinhala and Tamil communities. Even though the civil war has ended, occasional fragments of ethnic hostilities are still burning in the space created by the absence of a practical holistic approach and a good road map to resolve the conflicts.

Eventually, this situation might lead to some contingency or a trend towards a recreation of civil unrest and rivalries among these communities in the future. Consequently, it is a timely needed social necessity, a responsibility and a duty of all Sri Lankans to identify and be alert on the major causes which were instrumental to developing antagonistic rivalries between these groups in order to facilitate a long-lasting peace in the country. As the evaluation studies of Sri Lankan post war reconciliation points out "post-war transition is more complicated and difficult, following a unilateral war victory in competition with a complicit that ends in a negotiated peace settlement ..." [1]

Even though the government has taken various attempts to carry out reconstruction work, livelihood development, and peacebuilding in war-affected areas, their outcomes seem to be questionable in reaching the long-term reconciliation among these communities. Building sustainable peace in a conflict society needs to be accompanied by a comprehensive reconciliation strategy to forget the rivalries, be empathetic to each other, and create trust and understanding. The national reconciliation in Sri Lanka has largely concentrated on contracted institutional realizations, political (re)formation related to ethnic harmony and territorial-based devolution of power. These mechanisms and institutional forms are taking a prolonged time for finding remedial measures on crucial issues and thus leaving an unsolved problem in the country. [2]

Furthermore, there would be several structural impediments against the successful completion of the postwar reconciliation process. As per the findings of some peace researchers "much of the

cause for the failure of the reconciliation process in Sri Lanka was due to politically motivated-ethnic disagreements, prolonged issues relating to ethnic solitudes at a national level, and wide social and economic inequalities…" [3]

Therefore, peace builders of the country need to clearly envisage the situation in a way to avoid possible impediments in the peace process. The military defeat of the LTTE in the final battle in May 2009 which marked the end of the long war could be a potential turning point in ethnic relations and ethno-political dynamics of the country. "However, at this potential turning point whether history depends on the ability of various stakeholders of peace to use the new historical space to sustainable peace through national reconciliation and social cohesion should be found out…" [4]

Accordingly, it is necessary to learn the lessons from the past experience of the ongoing peace process in order to avoid the existing social, cultural, and political constraints. The broader scope of the study was classified into several specific sub-objectives as given below.

- Identifying the existing prejudices and social constraints that are emerging among Tamil and Sinhala communities
- Investigating the political and other constraints in the reconciliation process in war-affected areas.
- Identifying the limitations of methodological approaches of the post-war reconciliation process itself.
- Forwarding suitable proposals to overcome the existing constraints of the peace process to strengthen the social links among these communities.

## 2. Material and Methods

The literature review of this study revealed a vacuum of knowledge about the causes for delaying the post-war reconciliation process between Sinhala and Tamil communities in the war-affected areas. When opening scholarly overviews about Sri Lanka's reconciliation process during and aftermath of war, the reconciliation process seems to have been detached from the mainstreamed political process and remain unregulated in the country. [5]

Accordingly, it is directed to incorporate the study on a theoretical foundation based on the search of pro factors towards sustainable reconciliation.

The study employed a mixed-method approach incorporating both qualitative and quantitative data. "Mixed-methods researchers are pragmatic, collect both narrative and numerical data, employ both structured and emergent designs, analyze their data both via statistical and content analysis, and make meta-inferences as answers to their research questions by integrating the inferences gleaned from their qualitative and quantitative findings." [6]

A sample survey was conducted to accumulate quantitative information about the views and attitudes of people living in the war-affected areas. Such information was instrumental in understanding the nature of prejudices held by respective people against other communities, their willingness to reconciliation and the existing constraints against sustainable post-war reconciliation. Furthermore, Qualitative information was collected through key informant interviews to have an in-depth understanding of the research problem.

The study followed a judgmental sampling method to select war-affected six villages in Trincomalee district, Eastern Province where people belonging to both Sinhala and Tamil communities are living. They have also suffered heavily during the civil war. Among them, Kambakotte, Mailakudawewa, and Mahadiwulwewa were selected as dominant Sinhala Villages. Similarly, Nochchikulama, Shanthipuram, and Elaswaththa were selected to represent the villages dominated by Tamil people. Except Elaswaththa village, all the other villages are located in the close vicinity of the Morawewa Divisional Secretariat area.

**Map 1: Map of Morawewa Secretariat**


Elaswaththa is a village situated in the Trincomalee divisional secretariat of the district adjoining the Morawewa Divisional Secretariat area. A major reason to select this village to the sample is that it is almost inhabited by Tamil people who migrated from Nochchikulama and Shanthipuram during the war. They have lived in refugee camps during the war period.

Both Sinhala and Tamil people living in these proximal villages have had a high social integration and cohesion in cultural, economic, political, and other numerous social aspects prior to the civil war. In the initial visits to the study area, it was envisaged that both Sinhala and Tamil people in these villages have been returning to their normal way of living. Since the socio-economic relations between Tamil and Sinhala people living in these villages also had

been growing, this was considered as a positive sign of the possible avenues to reconciliation.

Primary data collection of the study was initially conducted with 200 randomly selected stratified sample representing respondents of these villages. It consisted of 100 respondents to represent the Sinhala community and the rest to represent the Tamil community. In this selection, socio-economic variables such as level of education, level of income, age, occupation, and gender were taken into particular consideration. A questionnaire was administered to collect necessary information from the selected sample.

The study also incorporated qualitative information collected through key informant interviews with 24 data providers. They represented12 data providers each from Sinhala and Tamil communities. The necessary primary data was collected using interview guidelines. In the process of formulating the questionnaire and interview guidelines, the themes such as the views on the impact of reconstruction, rehabilitation and reconciliation programs, existing prejudices towards each other on economic, infrastructural, and other resources, strengths and weaknesses of the methodologies adopted for the reconciliation, possible strategies to establish sustainable peace between Sinhala and Tamil ethnic communities, etc. were taken into main consideration.

Both questionnaire and interview guidelines were translated to Sinhala and Tamil languages accordingly. Questionnaires were filled out by respondents themselves with the proper guidance granted to them. The key informant interviews were electronically recorded with the consent of interviewees. The necessary secondary information was gathered via a variety of sources in a wide range of platforms, such as census reports, survey reports, government documents, and non-government reports.

## 3. Methods of Data Analysis

The quantitative information collected from the questionnaire was analyzed using simple statistical calculations such as means and percentages. The qualitative data collected from the interviews were evaluated incorporating a thematic analysis. In the formulation of such themes, objectives of the study were taken into consideration. Repeated reading and active reading were notable efforts taken to avoid any data being missed and to have a thorough grasp. Additional steps such as building a close relationship with the data, deciding the basic coding, finding the respective themes, studying the themes, naming and defining the themes were taken to the analysis and rearranging of the data in the study was also taken into consideration.

## 4. Results

It was realized that there are several impediments in operation at the ground level, national level, and organizational level for delaying the reconciliation process. In case of disturbances at the ground level is concerned, the prejudices remaining among Sinhalese and Tamil people towards each other have been significant. Such prejudices seem to be sustained by the majority and minority feelings inherent in them.

Sinhalese, being the majority group of the country shared a view that Tamils enjoyed many benefits from the post-war reconstruction and rehabilitation programs targeting to uplift the war-affected areas. Even Sinhala people living in war-affected areas share this prejudice which is leading to jealousy against Tamil people. Those ethnic groups who lived more harmoniously before the civil war are now hesitating to reconcile due to this existing suspicion and resentment.

Meanwhile, the study could reveal that Tamil people in the study area too share a prejudice towards Sinhala villagers living in the close vicinity. Such prejudices are based on the misunderstanding that Sinhalese as a majority group enjoy much freedom, political power, and better living than their counterparts. Many of them were of the view that Sinhalese people unlawfully exploit the financial and economic resources which were allocated for the development of Tamil communities. Also, some of the Tamil villagers were of the view that government too provided more development resources for Sinhala people who were not marginalized as the Tamils.

Furthermore, there were certain other political constraints found to be operating at the national and policy level contributing to the delay of the postwar reconciliation process. They were the outcomes of antagonistic and hegemonic attitudes in policy planning and implementation. The people's lack of participation in the decision making and implementation of reconciliation programs, much priority given to the infrastructure building in those war-affected areas, and the neglect of the root causes for the emergence of ethnicity-based rivalries were some of the instrumental factors for the achievement of sustainable peacebuilding in those areas.

Finally, at the organizational and institutional levels, there were certain limitations to provide a better path to reach the reconciliation targets. Reconciliation models show a greater dependency on humanity-based aspects such as psychological healing, giving forgiveness, truth-telling, etc. With the prioritization towards infrastructure building and reconstruction work, invisible bitter memories of the war and misunderstandings developed in peoples' minds have been mostly neglected. Therefore, it was revealed that the methodology adopted to reach the post-war reconciliation itself seemed to be a major limitation against its achievement.

## 5. Discussion

Despite the respective studies of the literature review, this study led us to study the delay of the post-war reconciliation concerning the context of the study. The discussion is based on the analysis of operational factors at three levels namely ground level, national level, and the organizational level. Initially, the ground level impediments against reaching sustainable peace and reconciliation were analyzed in terms of (a)existing prejudices towards each other by these ethnic groups and (b) the structural constraints in respective communities for rebuilding the social relationship.

Secondly, the national-level factors were analyzed in terms of political constraints confronted by peacebuilders. Finally, this study analyzed the methodological limitations of the reconciliation process itself in formulating and operating the reconciliation strategies at the grassroots level.

### 5.1.a Challenging Prejudices of Sinhala and Tamil communities towards each other

As per the theoretical explanations of prejudice, there is a mutually exclusive link between good relations and prejudice. The term "prejudice" can be defined as the bias that devalues people because of their perceived membership of a social group. Whenever, the growing prejudice exists among two communities their relationship is too found to be rivalries with fragmented, disconnected, and hostile interactions. "Any analysis of prejudice must begin with an analysis of the social context within which it arises. Intergroup relations, and prejudice in particular, need to be understood using multiple levels of analysis…" [7]

This study found that both Sinhala and Tamil people who lived in their respective villages had closely developed brotherhood and values before the civil war. Even though there were some cultural differences, they were not mattered for a communal and harmonious living among them. However, the decades-long armed conflict was instrumental to destroy the unity among them and growing resentments. It has been a crucial factor to grow antagonistic prejudices towards each other who were previously lived so close to each other.

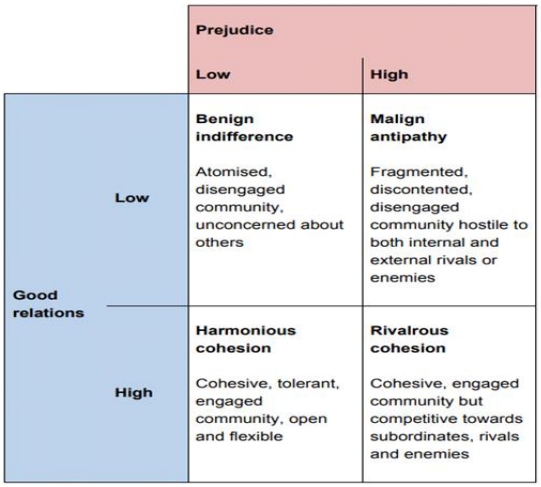


**Figure 01: A typology of good relations and prejudice [8]**

*Source: Dominic Abroms, 2010, p.35*

The field survey investigated the prejudicial views held by both Sinhala and Tami villagers towards each other in terms of sharing infrastructure facilities of the post-war reconstruction and access to educational facilities of the area.

**Table 1: Prejudicial Views of Sinhala and Tamil Villagers towards sharing Infrastructure Facilities**

| Prejudicial Views | Sinhala Villagers | Tamil Villagers |
|---|---|---|
| There is unjust in the distribution | 67% | 72% |
| There is no unjust in the distribution | 33% | 28% |
| Total | 100 | 100 |

*Source: Field Study 2019*

As per the above information, it is revealed that the majority of each ethnic community holds suspicion and resentment towards the other ethnic group that they are enjoying more benefits of the post-war reconstruction and other infrastructure facilities in the area. This misunderstanding seems to be highly held by Tamil people as they justify it as a result of the hegemony of the majority in the country. The observations during the fieldwork convinced that the resentment of Sinhala villagers towards Tamils were growing due to the misunderstanding that international agencies, as well as the government. They mostly look into the needs of Tamil people to satisfy the donor agencies.

Also, it revealed that certain bitter memories of Tamil villagers during the war have continuously affected them to stay lonely from the Sinhalese. As a Tamil School teacher expressed;

"Many of our belongings were robbed during the war by others. It is because we were living in refugee camps initially after the war. Therefore, we do not need to restore friendship with Sinhala people who were not helpful during the war period."

(KII-, Interviewed, 28th September 2019)

### 5.1.b Structural Constraints of Sinhala and Tamil Ethnic Communities to Restore the Social Linkages.

In protracted ethno-political conflicted societies, intergroup contacts and cooperative learning are supportive paths to reduce prejudices between the antagonist groups. Studying the following figures, the value of intergroup contacts to reduce prejudices promote positive attitudes and positive behavior for supportive relations can be understood.

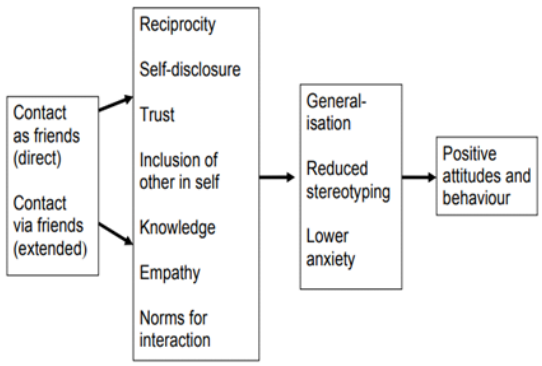


**Figure 2: Routes from intergroup contacts to lowered prejudice. [9]**

In the case of lowering the prejudices between rivalry groups in post-conflict societies, communication strategies have become so important. However, this study revealed that both Tamil and Sinhala villagers frequently find difficulties in communicating with other ethnic group members due to the language barrier. This has been a major constraint in promoting interactions and understanding between these groups as one Tamil school teacher pointed out.

"Once Sinhala students were invited to take part in some cultural activities in our school. Since we were unable to provide translators, those students could not understand the mission of this program as they did not know Tamil. (KII-, Interviewed on 28th September 2019).

Language and communication problem has become a barrier and an issue that should be addressed very deeply in the post-war reconciliation process. As one Sinhala elderly person pointed out

"I think Tamil people must learn Sinhala. Because this is a country where the majority represents Sinhalese. Similarly, Sinhala people also must learn Tamil, but they won't learn. However, it is not a must…" (KII-, Interviewed on -, 02nd October 2019).

Before the civil war, both Sinhala and Tamil villagers maintained close cultural contact in their day-to-day living. In Tamil dominant areas Sinhala people used to take part in religious and cultural ceremonies organized by Tamil people. Similarly, In Sinhala dominant villages too Tamil people used to participate in festivals and rituals in Buddhist Temples. However, in the post-war period, these respective communities used to live with their people due to certain resentments developed among them. Therefore, it is understood that cultural integration is the main component in a post-war reconciliation process to bring all communities to a common platform. This study revealed that the behavior pattern of both Sinhalese and Tamil people were not contributory for regaining the previously held social linkages among them. As one of the retired Sinhala government officers pointed out.

"I have a lot of experiences. Sinhala people go to Tamil kovils, their calibrations and common festivals. But I think Tamil people do not go to Sinhala temples and other festivals of Sinhala people. I think they ignore us and our culture…" (KII-, Interviewed on 04th October 2019).

Religious organizations, as well as schools, were found to be providing a better platform for both Sinhala and Tamil people to develop brotherhood throughout their life in the border villages before the civil war. Even though many infrastructure facilities were not provided in these schools, they were accepted and utilized equally for their educational purposes. However, the traditional views of sharing and simplicity seem to have been evaporated from these communities due to unknown reasons. As per the attitude of a Tamil villager.

"All the infrastructure facilities are dumped into Sinhalese schools whereas Tamil students not getting even minimum requirements to study. And, in the reconciliation process also we don't see Sinhala people use education to succeed the peacebuilding process…" (KII-, Interviewed on 05th September 2019)

### 5.2 Political constraints in the post-war reconciliation process at national level

Restoration of peace and establishing reconciliation in a post-conflict society requires a genuine will of the government in power. They have to be empathetic to the affected communities and restore their rights and livelihood in order to heal the

wounds in their minds. Also, the government should be capable of bringing all the relevant stakeholders into a common platform for removing existing barriers and constraints to reach the targets.

Restoring the moral order that has broken down requires that "justice be done". A successor government owes it, above all, as a moral obligation to the victims of the repressive system. Post-conflict justice serves to heal the wounds and to repair the private and public damage done by the antecedent regime. As a sort of ritual cleansing process, it also paves the way for a moral and political renaissance. [10].

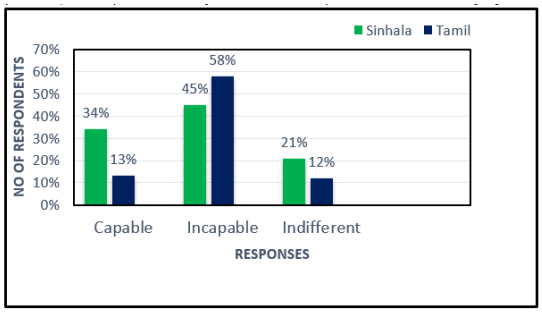


**Figure 3: Peoples' view on capability of politicians to establish reconciliation.**
*Source: Field Data*

This information shows that majority of both Sinhala and Tamil respondents were of the view that politicians are not having the capability to restore peace and establish reconciliation in this post-conflict society. This negative attitude towards politicians seems to be relatively high. among Tamil villagers who are still possessing antagonistic views towards Sinhala people in general. Therefore, it is envisaged that until positive attitudes of people are developed towards politicians in the country their active participation in the reconciliation process would not be realized successfully.

"To date, reconciliation in Sri Lanka has not been well integrated into the conflict transformation process, and it is fair to say that reconciliation initiatives have been poorly planned, with little effort made to include a political, socio-economic, religious or cultural focus…" [11]

It is also a basic requirement that political leadership should take necessary steps for people to forget the bitter past war memories remaining in their hearts and encourage them to forgive each other who were previously held ethnic rivalries. This study revealed that certain efforts of both Sinhala and Tamil politicians to construct war memorial statues to commemorate their deceased soldiers in the war and the annual celebrations of war victory or war heroes etc. have been aimed at gaining narrow political achievements. Sometimes government efforts to disturb the celebrat ions of LTTE war heroes have resulted in the resentments of the Tamil community.

As per an interview with a former carder of L.T.T.E. also will be helpful to understand the unfavorable fact regarding such involvement of the Sri Lankan government.

*"I think the government should not disturb to the celebrations or rituals of Tamil people are such kind of behavior people should be given the psychological freedom…" (KII-, Interviewed on 28th September 2019).*

According to the theory of memory, memory projects may delay in the reconciliation efforts if they are one-side, if they fuel controversies or celebrate extremist or totalitarian ideologies [12]. It could be revealed in the study also that, memorization activities have taken place even after many years after the war. The following pictures based on the memory projects can be identified as pro-factors for the delay of the post-war reconciliation process.

**Figure 4: An Occasion of Ceremony near a Monument by Sri Lankan Army**
*Source: Field Data*

**Figure 5: The Recently Built Monument in the University of Jaffna to Memorize Died Tamil People in the War.** *Source: Field Data*

### 5.3 Methodological limitations of reconciliation process itself in formulating and operating the reconciliation strategies at grassroots level

Reconciliation is defined by its Hebrew root word 'Tikuum Olam' which means a three-part process of HEAL, REPAIR AND TRANSFORM. In

order to HEAL the impact of tribal or ethnic division, civil war and violence, a process of acknowledging the evils that have been committed is essential. History has proven that grievances ignored will eventually destroy the potential for a sustainable peace. Authentic reconciliation and healing are not possible without justice and equality. This is a fundamental requirement for reconciliation. [13]

It is a well-known fact that Sri Lankan government too initiated several development strategies based on reconstruction, resettlement, and reconciliation in the post-conflict society. Those infrastructure facilities including road networks, electricity, water supply, etc. have been restored to ensure the normal livelihood of people in war-affected areas. However, it is a timely necessity to evaluate the progress of the reconciliation programs in terms of the methodologies adopted in the process and their ability to involve the peoples' participation successfully.

Those reconciliation programs to be effective in a post-conflict society should link with several other inputs instrumental to peacebuilding. Among them, psychological and humanitarian components such as truth-telling, and healing are very important pre-requirements for its successful implementation. The following figure depicts the integrated components of the reconciliation process.

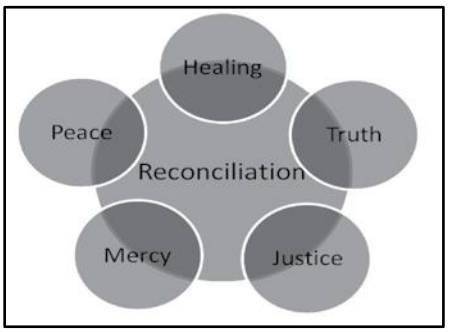


**Figure 6: Integrated Components of Reconciliation [14]**

One of the incumbents of Tamil temple was of the view that some essential components of a reconciliation process seem to be missing in the ongoing peace-building programs.

*"The government must engage in peacebuilding with an open heart and with spiritual pleasure. I think the healing process of current reconciliation programs seems to be missing. It is a big problem …" (KII-, Interviewed on 04th September 2019)*

As per the Tamil respondents of the study, most of the programs which were implemented in the postwar period in the area are not based on the need for reconciliation.

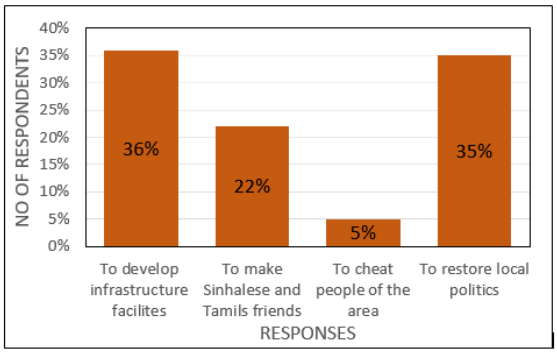


**Figure 7: Views of Tamil Respondents about the Reconciliation Programs** *Source: Field Data*

According to this figure, the majority of them (71%) assessed these programs are either targeted to infrastructure building or to restore local politics. Only a few (22%) of the respondents agreed that such programs were instrumental to restore the friendship among Tamil and Sinhala people as one GN Officer pointed out

*"Almost all reconciliation projects have been planned by the government officers themselves at the top level. They have neither knowledgeable about the felt needs of the affected areas nor made a consultation with the stakeholders in the affected areas before planning these programs. Similarly, they have not seen restoring social harmony between Sinhala and Tamil people as a felt need of these areas "*

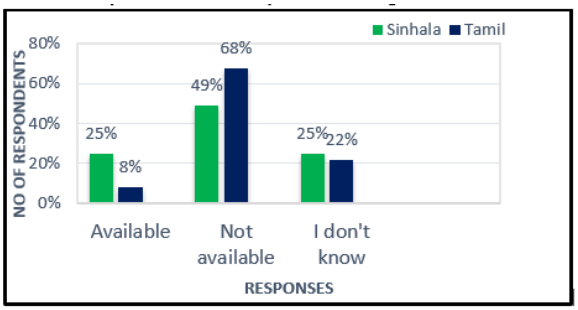


**Figure 8: The Attitudes of Both Communities on Availability of Long-Term Programs in Media to Help Sinhala People and Tamil People to Live Together.** *Source: Field Data*

Mass media and mass communication are two important stakeholders of reconciliation between two antagonist groups, as they can always communicate positive messages for bringing them to a common platform.

Media helps dissipate the rumors and propaganda disseminated by extremists, which feed social and political tensions. It also creates a space for articulating diverse viewpoints, approaches, and opinions. Above all, it contributes to both transparency and accountability in public affairs,

exerting pressure on political and social leaders to behave in a responsible way. [15]

Television, radio, and newspapers have been at the forefront in this process and are considered to be major stakeholders in peacebuilding process. However, some agents of media were found to be violating media ethics and the responsibilities of serving positively towards reconciliation during the past.

Some of the university academics have been involved in the evaluation of the progress of ongoing reconciliation programs. As per the views of one of such Sinhala universities, academics pointed out……

*"Progress and continuation of dialogues regarding the reconciliation process cannot be heard or seen in the country. And, the success of dialogues in the reconciliation processes of international society are not taken by Sri Lanka and no programs for that…" (KII-, Interviewed on 05th October 2019)*

Based on the data of Table 3, it is revealed that both Sinhala and Tamil ethnic communities agree on the unavailability of a well plan to reconcile people.

**Table 2: Availability of planned strategies to restore friendship between Sinhala and Tamil people**

| Views of People | Sinhala Respondents | Tamil Respondents |
|---|---|---|
| There are well planned programs | 30 | 22 |
| There are no well-planned programs | 52 | 44 |
| Don't know | 18 | 34 |
| Total | 100 | 100 |

Reconciliation programs should be carried out with the participation of people in war affected areas since they are the key stakeholders of this process. It is mainly due to the fact the needs and priorities of such people need to be included ensuring their ability to share the available benefits. Accordingly, it shows that

## 6.Conclusion

Following the military victory of the war, the Sri Lankan government has been implementing several strategies targeting reconstruction, resettlement, and reconciliation in the war-affected areas. *Reconciliation strategies that were targeting the restoration of peace and* goodwill among Sinhala and Tamil communities have been implemented with the involvement of government and non-governmental institutions. The findings of the study revealed that various socio-economic and political constraints are found to be impeding the successful implementation of these targets. Among them, first, the ground level impediments operating in terms of existing prejudices among Sinhala and Tamil communities towards each other and structural constraints to restore social linkages have been prominent. These prejudices were the outcomes of misunderstanding toward other communities that they are enjoying more benefits of the economic resources and the post-war development programs.

The structural constraints of the reconciliation process signify the existing barriers based on language and culture base differences that were hindering opportunities to interact between these communities. Secondly, the national-level factors in terms of political constraints to reach the final destination of sustainable peace were investigated. Finally, it was assessed that the methodological feasibility of the strategies affected those programs. It is revealed that lack of well-planned road map based on humanitarian requirements seems to be lacking as politicians have been more interested in the implementation of reconstruction and resettlement requirements. Also, political parties who celebrate war victory or war heroes were found to be stimulating resentments among Sinhala and Tamil groups. Finally, the methodological limitations of the reconciliation projects are to formulate and implement strategies to win the participation of both Sinhala and Tamil at the grass-root level have impeded reaching their targets. Accordingly, the study concluded that reconciliation programs are needed to be formulated, implemented, and monitored continuously with the real participation of both Sinhala and Tamil people in the war affected areas to reach sustainable peace in the post-conflict society in Sri Lanka.

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# The Population Trends and Distribution of White Browed Fantail (*Rhipidura aureola*) in Sri Lanka

[*1]Bopitiya Gamage PTS & [2]Wijeweera WPSN

[*1]*Meemanage Wattha, Godagama, Matara, Sri Lanka*

[2]*Department of Zoology, University of Ruhuna, Matara, Sri Lanka*

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**[*]Corresponding Author**
*Email:*
surendi87nisha@gmail.com

**ABSTRACT**

White Browed Fantail (WBF) is a small bird with a characteristic fan-like tail. They inhabit both wet and dry zones of Sri Lanka covering coastal and inland regions. However, there are no studies related to its distribution within the island. Therefore, our study was aimed at its distribution in Sri Lanka along with its seasonal variation and specific behavioral patterns in Kirala Kele Sanctuary. We extracted 5403 occurrence records of WBF from eBird from 1975 to 2020 and plotted distribution maps. To study the seasonal variation of the bird, 336 field visits were conducted from 2018 January to 2021 July in Kirala Kele sanctuary (5.9790 N, 80.5130 E). The occurrence records show, the bird gradually spread within the island over the past 45 years. They were less abundant in the Northern and Eastern parts of the country. The occurrence records (n=88) revealed that WBF inhabited the Kirala Kele sanctuary throughout the year except for December. They use Kirala kele as a breeding and feeding ground. At present, their temporal variations show they appear in higher abundance for longer periods of the year in Kirala Kele. They show mixed flock foraging with Oriental Magpie Robin, White-bellied Drongo, Yellow-billed Babbler, and Common Tailorbird. In addition to flying insects, they highly prefer ants.

## 1. Introduction

White Browed Fantail (WBF) is a small passerine bird that belongs to Family Rhipiduridae. Their dorsal body parts are dull in color with long broad white eyebrows. It spreads its tail, like a fan as it got the name “fantail” [1, 2]. It is a native resident of Bangladesh, Burma, China as well as Sri Lanka [2]. They expand their habitats from dry, open woods along the deciduous forest to agricultural lands as well as home gardens [2-5]. As behavioral studies are closely linked with conservation biology [6], there are few research studies on the behavioral ecology of WBF [1,6]. However, studies on related to its current status or population trends in Sri Lanka are lacking. As the population trend plays a key role in species risk assessment and conservation planning, the studies related to the species status/ population trend is important [7]. Therefore, our study aimed to understand the historical and present status of WBF in Sri Lanka and provide incidentally observed behavioral notes, and their seasonal variation in Kirala Kele Sanctuary of Sri Lanka.

## 2. Material and Methods

The status of WBF in Sri Lanka was analyzed from 5403 occurrence records obtained from eBird over a period of 45 years and distribution graphs were plotted (Figure 1). To observe seasonal variation and behaviors of WBF, a study was conducted in Kirala Kele Sanctuary (5.9790 N, 80.5130 E) in Southern Province of Sri Lanka. The field visits were conducted over 3.5 years (2018 January-2021 July) and obtained 88 occurrence records of WBF by covering 336 field visits. Random field visits were conducted on both weekends and weekdays in the morning (6.00 am-8.00 am) or evening (4.00 pm-6.00 pm) sessions. Point counts were done in four (5.59 N, 80.3131 E / 5.5839 N, 80.3151 E / 5.5806 N, 80.3119 E / 5.5816 N, 80.3220 E) observation centers.

Continuing sightings in the same point counts over consecutive or recent days were considered as a single sighting to avoid possibly repeat counting the same individuals. Also, in the absence of systematic census data, maximum numbers of WBF seen for each month were used to estimate the population [8]. During field visits, their behavior was observed using binoculars and visually.

## 3. Results and Discussion

### 3.1 Historical and current status

According to previous records, the bird is more common in the Uva province of Sri Lanka [9]. They were abundant in jungles between the Haputhale mountains and the southeast coast and eastern part of the low country while rare in Hambantota and Galle districts of the southern province of Sri Lanka [9]. In 1931, the bird was common in the Hambantota district, and the scattered populations were in Galle and Matara districts [10]. In the 1970s, the bird was widespread in uva, eastern, western, central, sabaragamuwa, and southern provinces of the country [11].

Within the last forty-five years (1975-2020), WBF gradually spread throughout the island. They were more abundant in central and southern regions and less abundant in northern and eastern parts of the country (Figure 1). This observation might occur due to the prevailing war condition in the past decade where birders were unable to visit the northern and eastern land of the island.

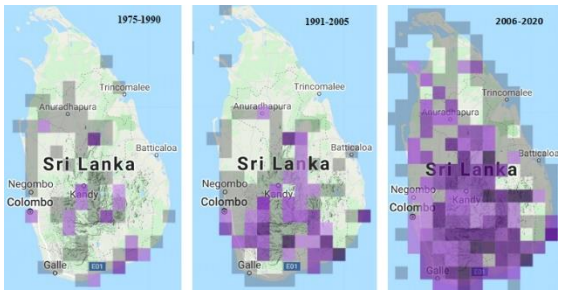


**Figure 1: White Browed Fantail progression the past 45 years (1975-2020) within Sri Lanka. Image provided from eBird (www.eBird.org) and generated on 24 July 2021.**

Out of 336 field visits of Kirala Kele sanctuary, the White Broad Fantail only recorded 88 field visits representing only 25.9% sightings. An avifaunal study in Kirala kele revealed that WBF was very common during 2002-2003 and that status was shifted to uncommon category during 2018-2021 [12]. However, in most of the sightings (88.5%), the species appeared as a single bird or a pair.

### 3.2 Residential status

WBF was recorded in Kirala Kele sanctuary every month except December. Their peak abundance was in June. They were rarely observed in November and disappeared in December (Figure 2), and maybe they moved to another habitat during December.

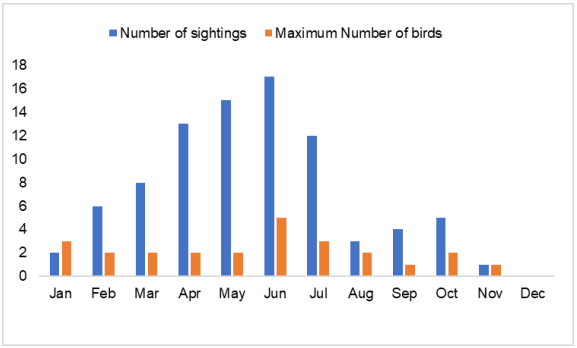


**Figure 2: Temporal distribution of White Browed Fantail sight records and maximum number of White Browed Fantail observed per month in Kirala Kele Sanctuary (2018-2021)**

### 3.3 Seasonal variation of WBF in Kirala Kele Sanctuary

In 2018, the bird was recorded only in two months; February and October. In 2019 and 2020, the sightings of WBF were 3 -4 months per year. From January to July 2021, the bird was recorded in higher abundance continuously throughout the study period (Figure 3).

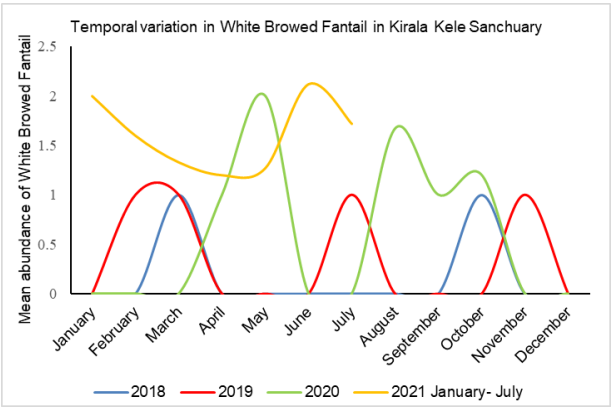


**Figure 3: Mean abundance of White Browed Fantail over a period of fourty three month (January 2018- July 2021) in Kirala Kele sanctuary**

### 3.4 Behavior

White-browed Fantail usually observed as a single bird or pair-vise, a female and a male. As they are territorial birds, mating pairs do not allow any other individuals of its own species to enter into their territory. Even they show territorial behavior on inter species also. Chasing movements upon the inter and intra species is well observed. It is a very active bird with high vocalization. They have a unique song having 4-7 melodious whistling notes [13]. Male birds perch on open grounds or a branch without leaves and sing during the mornings and the

evenings. It produces a unique harsh call, “switch-wich” which is easy to identify the bird’s presence even without seeing it.

Their breeding season is in between January to July. They build a nest approximately 8-10 feet above the ground. It is a very neatly finished cup-shaped nest with fine fibers, rootlets, and cobwebs. Both male and female birds engage in nest building that lasts 9-13 days. Peak egg-laying period is from April to May, and females lay 2-3 oval-shaped eggs. Same breeding pair reuse the nest (if the nest remain in good condition) in next breeding season also. The nest failure rate of WBF is higher due to domestic cats, crows, coucals, lizards, tree snakes, predatory birds, and heavy rains [5,10]. In addition, they showed aggression towards interspecies as well as intraspecies during the breeding season. Their Nests were visible and located 3-4 meters above the ground.

WBF appears as a mixed flock during foraging. Such a flock consists of oriental Magpie Robin, White-bellied Drongo, Yellow-billed Babbler, and Common Tailorbird. Similarly, the mixed flocks of WBF in Myanmar consist of Beavan’s Prinia, Common Prinia, Common Tailorbird, Chestnut-bellied Nuthatches, and Radders’ Warbler [14]. The study further explains that they show a commensal relationship with Warblers and Nuthatches. However, if the insects are scarce, WBF steals the prey from Nuthatches, shifting their relationship from commensal to kleptoparasitism [14]. In addition to insects, we observed that they highly preferred ants. They spread their tail like a fan, flapped, and jumped to flush away the ants that hide under the leaf litter and eat them.

In summary, our records and eBird data indicate that they are now more widespread in all nine provinces of Sri Lanka. Also, they are observed in Kirala kele sanctuary throughout the year except in December. From January- June 2021, the species was continuously observed within the sanctuary.

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# Overview of e-Cigarettes and e-Liquids

Perera SD* & Dulmini ADT

*Department of Chemistry, The Open University of Sri Lanka, Nawala, Sri Lanka*

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*email: ksper@ou.ac.lk

**ABSTRACT**

Electronic cigarettes (ENDS) were introduced to the market particularly for addicted smokers to quit the habit of conventional tobacco smoking. The process behind e-cigarettes is heating an e-liquid/juice using a battery to generate an aerosol or vapor. There are four generations of electronic cigarettes in the market; cigar like, tanks, mods and pods. The evolution of these models of electronic cigarettes has affected the young generation for two decades. Most electronic cigarette manufacturers add nicotine, flavors, other addictive chemicals and sometimes illicit products to e-liquids; thus, e-cigarettes have become a global health issue. Scientists have revealed that the content of e-liquids can create many long-term and short-term health problems including EVALI. Thus, many countries are in the process of regulating the market of electronic cigarettes. e-Cigarettes are new to the Sri Lankan society and they can be easily embraced by the younger generation due to unawareness of the dark side of these products. In this overview, components of e-cigarettes, chemicals present in e-liquids, generation of e-cigarettes, growth of e-cigarette market, and health concerns associated with vaping of e-cigarettes are presented.

## Introduction

Since 1950s, the smoking of tobacco has risen as a habit that reflected the status and emotions to others, until scientists revealed the dangers of it. One tobacco cigarette consists of or produces more than 50 toxic chemicals [1,2]. Some toxic chemicals include alkaloids (nicotine, anatabine); non-volatiles: 4-(N-nitroso-N-methyl aminobutyric acid); volatiles: (N-nitrosoethylmethyl amine, N-nitrosodiethylamine); polyaromatic hydrocarbons (PAHs), acetonitrile, acrylonitrile, and heavy metals, Pb, As, Cd *etc*. [2].

More people are dying from conventional tobacco smoking than from wars, accidents, and natural disasters. Thus, the introduction of Electronic Nicotine Dispensing Systems (ENDS), commonly known as electronic cigarettes (e-cigarettes), is considered as a “savior” for addicted tobacco smokers [3]. They appeared on the market more than a decade ago. Nowadays e-cigarettes are available in Sri Lanka and public awareness is mandatory before it becomes a threat to our younger generation.

## Conventional puff to electronic puff

Tobacco cigarettes are simply known as conventional cigarettes. All types of tobaccos (*e.g*., cigar, pipes, smokeless tobacco - chewing tobacco and snuff) are dangerous. It is a famous secret that these cause all kind of health risks including; cardiovascular diseases, lung diseases, cancers, infertility, miscarriages, low bone density, gum diseases, tooth loss, immune system dysfunction, sexual impotence in men, increase risk for hip fracture in women *etc.* [2,4].

According to World Health Organization, smokers are more susceptible to be infected by both bacteria and viruses. Therefore, Covid 19 virus can easily affect the smoker’s weak respiratory and immunity systems due to his/her smoking behaviors such as smoker’s hand to mouth action, sharing of pipes *etc.* [5].

e-Cigarettes and vaping are novel alternatives for ex-smokers and smokers who want to give up smoking. Most of these devices have in-built tank or cartridge, and the nicotine levels can be changed according to the nicotine doses prescribed by the doctor. The ultimate goal of using e-cigarettes is to quit the more harmful tobacco smoking forever. However, nowadays, most of the non-smokers specially teenagers are trying out e-cigarettes due to peer pressure and get themselves exposed to this dangerous experiment. Vaping can lead to nicotine addiction and increased risk for addiction to other drugs.

## What is an “e-cigarette”?

Vaping is the inhalation of a heated aerosol (*i.e*., vapor). e-Cigarette is a hand-held electronic device that can produce an aerosol by heating an “e-liquid"

using a battery. Vaping is probably safer than combustible tobacco use, although the long-term health impacts of vaping are unknown [3].

There are more than 7000 flavored e-liquids available in the market [3,6] and fruit and mint flavors are popular among US youth [7]. JUUL (USA) is the leading company that provides more than 19% of e-cigarettes and related products to the global market. e-Cigarettes are produced by more than 400 companies all over the world (*e.g*., China - Aleadar, Artery, Asvape, Ovanty, Freemax, Eleaf, VooPoo, Wismec, Rincoe, Mimo; USA - Asmodus, dotMod, Hexohm, Vgod, Volta; UK - Nanostix, Relx, RevTech; Korea - Just fog, Lil; Malaysia - NCIG; Taiwan - Suorin *etc*.) [8].

### Components of an e-cigarette

An e-cigarette is composed of five main parts; mouthpiece, e-liquid chamber, battery, atomizer and a switch [9,10].


**Figure 1 Main components of an e-cigarette** (https://www.vapebrothers.com/in-focus/what-is-an-electronic-cigarette/)

The atomizer plays a vital role in energy transition and making the aerosols. That means it transmits and converts electricity (which is supplied by a battery) into heat. Sometimes, heating wires (*e.g.,* nichrome, pure Ni and Ti, stainless steel *etc*.) act as atomizers and these may enhance the metal toxicity [9,10].

There are several techniques that can be used to produce the vape, such as dripping, dabbing *etc*. Dripping method is the most common technique applied in many e-cigarettes, since it gives a thick aerosol cloud, a stronger throat hit and an intense flavor. In this method, e-liquid drips directly on to the heating coil. Generally, the cotton wool-like material (ekowool, silica fiber, and rayon fibers) called "wick" is soaked by the e-liquid, thus facilitating dripping. Dabbing is one of the methods that produce vapor from cannabis [10].

### Evolution of e-cigarette

All e-cigarettes can be categorized into four generations (Figure 2). The first generation of e-cigarettes appeared like a ciga. Its cartridge and atomizer are molded into one piece; thus, it is known as cartomizer. This type of e-cigarettes is reusable [9,10].


(A) - 1st Generation - Disposable/cig like
(B) - 2nd Generation - Medium size/ rechargeable/refillable
(C) - 3rd Generation - MOD
(D) - 4th Generation - POD

**Figure 2 Four generations of e-cigarettes**

(https://www.ncbi.nlm.nih.gov/books/NBK555596/figure/ch6.fig1/)

Tank type e-cigarettes belong to the second generation. This product is composed of more attractive features such as having a battery with larger capacity which can be controlled by on/off switch, separate refillable e-liquid cartridge *etc.* This is much effective towards the cessation of smoking as the nicotine concentration can be reduced by varying the heat generated by the power output [9,10].

"MOD" (modified or modular e-cigarette) represents the third generation of e-cigarettes and it consists of adjustable atomizer, cartridge and modifiable battery which can adjust the voltage. This refillable and rechargeable mod can control the release of aerosol. But the main disadvantage of this product is production of carcinogenic carbonyls by hotter e-liquids [8-10].

Fourth generation is represented by "POD**"**. Its battery, atomizer and mouthpiece are combined into one piece, and cartridge is replaceable. It produces higher nicotine concentration compared to that of mods, even though it generates less carbonyl content as it needs less power [7,9]. Pods are popular among young people in US, while adults and older people in England prefer tanks [9].

### Constituents of "e-liquid"

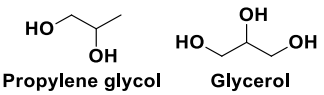
Main constituents that can be found in an e-liquid are,

- Propylene glycol or glycerine (solvent)
- Nicotine (not always)
- Particles - Silicate (size < 2.5 µm, *e.g*., $PM_{2.5}$) [3]
- Heavy metals - Pb, Cr, Ag, Ni, Al, Sn

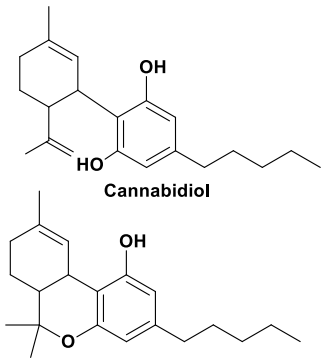
- Flavorings (*e.g*., taste like menthol, mint, clove or spice, alcohol (wine, cognac), candy, fruit, chocolate, *etc*.) [3, 7]

The other constituents found in the vape are aldehydes (acetaldehyde or formaldehyde), alkaloids (anabasine, anatabine, nornicotine), butadiene, diacetyl and acetyl propionyl, ethanol, N-nitrosamine, polyaromatic hydrocarbons, propylene glycol, glycerin sucrose, propyleneoxide, flavors (menthol), volatile organic compounds (VOCs) (methanol, ethanol, acrylamide, acrylonitrile, benzene, acrolein, pyrazine, pyridine, styrene, toluene, xylene), vanillin, limonene, and vitamin-E acetate [3,11-15].


Generally, propylene glycol and vegetable glycerin or glycerol play the role of the solvent in e-liquid [5,12,16].



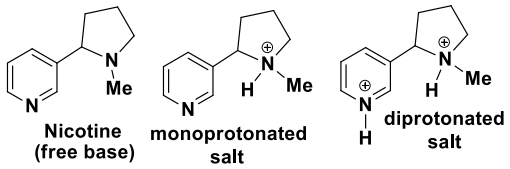

Sometimes e-liquid may contain cannabidiol, tetrahydrocannabinol (THC), or synthetic cannabinoids [10].




Cannabis oil (hash oil) can be extracted by using different organic solvents such as naphtha, petroleum ether, olive oils *etc*. It is added to e-liquids containing limonene or lecithin to enhance the miscibility and to mask the characteristic strong odor of the cannabis oil [10].

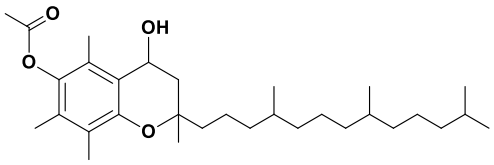
### Nicotine and Nicotine Salt

Nicotine is one of the most addictive chemicals to human beings and it is a weak base ($pK_a = 8$), which is capable of producing excessive metabolites in the liver. Nicotine stimulates the adrenal glands to release the hormone epinephrine (adrenaline) which increases the levels of a chemical messenger in the brain called dopamine. In a conventional tobacco cigarette, 10-15 mg of nicotine is present while 6-24 mg/ml in an e-cigarette. According to EU-TPD (European Tobacco Product Directive) regulation limits, maximum nicotine concentration in an e-liquid should be 20 mg/ml [9]. Some researchers have revealed that e-cigarette companies are misleading the society by displaying less nicotine concentrations on their labels than the actual nicotine concentration present in the e-liquid. Reports suggest that non-nicotine e-liquids can also be topped up with nicotine shots [3,11].

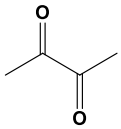



Not only nicotine stimulates the release of adrenaline but also increases the blood pressure. Dizziness, irregular and disturbed sleep, depression, anxiety, indigestion, diarrhea, dry mouth and nausea are common symptoms of the nicotine toxicity. Nicotine can go through to a child from a breastfeeding mother as it circulates through the blood stream. Hence, the child will suffer from restless, rapid increase of heartbeat, vomiting, interrupted sleep and diarrhea [11,12,17].

Vitamin-E or Tocopherol acetate is another component present in illicit e-liquids. Though Vitamin-E is safe to use as a dermatological product (skin cream) and in food, the vape of vitamin-E may turn into a sticky oil substance inside the lungs. e-Liquids containing Marijuana oil can be potentially fatal [13].




$PM_{2.5}$ sized particles (particles that are 2.5 microns or less in diameter) in e-liquids can pass through the air sacs and circulate in the body causing heart attacks, lung cancer and asthma. Heavy metals and other VOCs are bio-hazards. Components in e-cigarette aerosols can interact with each other to produce harmful substances such as formaldehyde, acetaldehyde *etc*. Diacetyl is a food sweetener which is not harmful to the digestive system but its vapor can cause “popcorn worker’s lung disease”. Recently scientists have discovered that e-cigarettes are causative to cytotoxicity, diseases in pulmonary and cardiovascular systems *etc*. [11,14,15,22,23]. Passive vaping may cause short term lung obstructions [14,16].



Diacetyl

JUUL was the first company that introduced the nicotine salt, instead of free-base nicotine. Newly arrived Pods contain nicotine salts produced by mixing nicotine and benzoic acid [12]. It has a pH similar to the extravascular fluid in the lung, thus, puffs with higher concentration of nicotine can be taken in without any throat irritation. Nicotine salts are found to be more harmful than free-base nicotine, because they increase the absorption of nicotine into the blood stream immediately [12].

## Global Threat

The global market for e-cigarettes has multiplied from around 50 million USD in 2005 to over 20 billion in 2019 and is expected to grow to 34 billion by 2024 [18]. Today, e-cigarette companies are targeting teenagers and they are introducing eye-catching e-cigarette models with different flavors [12,19]. Because of these misleading labels and mesmerizing advertisements, the young generation is lost among the clouds.

In 2020, e-cigarette use among high school students (grade 9-12) and middle school students (grade 6-8) in US were 19.6% and 4.7%, respectively [7]. Many teenagers do not even realize that vaping-cartridges contain nicotine, and assume the pods contain only flavors. The easy availability of these electronic devices, alluring advertisements, various sweet e-liquid flavors, and the belief that they are safer than cigarettes have helped make them appealing to this age group [13].

Under U.S. Food and Drug Administration (FDA) regulations designed to protect the health of young Americans, minors can no longer buy e-cigarettes in stores or online. The FDA now regulates the manufacture, import, packaging, labeling, advertising, promotion, sale, and distribution of e-cigarettes [12,13].

In 2019, sixty-eight (68) US e-cigarette users died and over 2800 consumers were hospitalized due to lung injuries and acute pneumonia (EVALI) associated with vaping of e-cigarettes [8].

Teenagers can easily get addicted to illicit e-liquid products containing THC (the main psychotropic ingredient in marijuana), butane and hash oils (concentrated THC) *etc*., although under the Federal Law in US, cannabis products over 0.3% THC are illegal [10].

In 2019, e-cigarette market in Southeast Asia was worth 595 million USD and projected to grow to 766 million by 2023 [8]. The youth in Southeast Asian countries such as Malaysia, Indonesia, Philippine, Vietnam, Taiwan, Hong-Kong has become the victims of e-cigarettes. Singapore, Laos, Cambodia have imposed a ban on import and sale of e-cigarettes in 2020 [8,18]. We are not aware of any reports on the use of e-cigarettes by Sri Lankan youth.

## Meaning of new words and abbreviations

**Atomizer** - A compartment of an e-cigarettes where the electric energy is converted into heat to produce vapor from e-liquids

**Cartomizer** - It is a type of atomizer that is pre-filled with e-liquid which can be replaceable. Cartomizer is usually the easiest type to operate [10]

**Electronic cigarette** - A hand-held electronic device that can produce an aerosol by heating an “e-liquid" using a battery.

**e-Liquid** - A liquid used to produce aerosol in e-cigarettes.

**MOD** - Short for modified e-cigarette, that can be modified according to user preferences. They are larger than a vape pen and produce more vapor

**POD** - It is a mini vape based on a two-part system: a pod filled with vape juice that snaps into a small battery [10]

**Vaping** - Inhalation of a heated aerosol (*i.e*., vapor)

**ENDS** - Electronic Nicotine Dispensing Systems

**EVALI** - E-cigarette, or vaping, product use associated lung injury [20]

**THC** - Tetrahydrocannabinol is the main psychoactive component of cannabis

## Conclusion

There are four generations of electronic cigarettes in the market; cigar like, tanks, mods and pods. The proper use of e-cigarettes may help lower nicotine-cravings in addicted smokers which may lead to quitting of the habit of smoking. However, e-cigarettes are not an FDA-approved quit aid, and there is no conclusive scientific evidence on the effectiveness of vaping for long-term smoking cessation. Addition of nicotine, flavors, other addictive chemicals and illicit products to e-liquids made the e-cigarette a potential health problem, particularly for the younger generation. Strict regulatory actions should be taken by governments and health authorities to prevent e-cigarette use from becoming a health issue in Southeast Asia and Sri Lanka in the future. People must understand that e-cigarettes and vaping are as dreadful as conventional cigarettes.

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# Unmanned Aerial Vehicles (UAV) in Precision Agriculture: Applications, challenges, and Future Perspectives

[1]Priyankara Prabath, [*1,2]Perera TANT, [1]Ruwanpathirana, [1]Jayasinghe GY, [3]Morimoto T

*[1]Faculty of Agriculture, University of Ruhuna, Mapalana, Kamburupitiya 81100, Sri Lanka.*

*[2]Department of Export Agriculture, Faculty of Animal Science and Export Agriculture, Uva Wellassa University, Passara Road, 90000 Badulla, Sri Lanka (ORCID - 0000-0001-9867-2056).*

*[3]Faculty of Life and Environmental Sciences, University of Tsukuba, 1-1-1, Tennodai, Tsukuba, Ibaraki 305-8572, Japan.*

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***Corresponding Author**
*Email: nilusha@uwu.ac.lk*

**ABSTRACT**

Precision Agriculture (PA) is being revolutionized by unmanned aerial vehicles (UAVs), which enable for more effective resource utilization. PA will reach every corner of Sri Lanka in the next years. As a result, the purpose of this research is to (a) categorize UAVs in agriculture based on their performance characteristics, and (b) examine future challenges and research opportunities that will lead to the long-term deployment of UAVs in PA. The types, applications, advantages, disadvantages, opportunities, and potential dangers of using UAVs in PA were critically reviewed, examined, and evaluated using scholarly research articles, conference proceeding papers, and previously published literature from the past fifteen years, and information gaps were identified. UAVs have been classified based on their major performance parameters such as weight, endurance and range, altitude, wing loading, engine type, and power/thrust loading. UAVs are more appropriate in agricultural practices due to their high spatial resolution and fast turnaround capabilities, as well as their low operating costs and ease of use. Livestock and wildlife management, crop monitoring, chemical and fertilizer application, weed detection, field mapping, and soil condition assessment are the major applications of UAVs. Some of the primary constraints observed are the capture and availability of images on time, a lack of high spatial resolution images, challenges with image interpretation, and data extraction. Overall, UAVs are one of the most important technologies that transform traditional cultivation practices into a new perspective of intelligence in PA.

## 1. Introduction

Climate change has a severe influence on food security, with 815 million people suffering from chronic hunger, with Asia accounting for 64% of the total. To feed the growing population, food production must almost double by 2050. Nonetheless, land and water resources are becoming increasingly under threat [1]. As a result, farming communities and agricultural workers must respond to climate change and other challenges. In this regard, information and communication tools, as well as precision technologies, play a significant role in improving decision making through reliable, accurate, and fast information technologies [2].

Precision farming is now focused on developing smart applications for agricultural resource management. It seeks to boost production, profitability, and environmental preservation [3]. The primary steps of precision agriculture include data gathering, mapping of field variability, decision making, and management techniques [4]. Autonomous aircraft can be defined as an improved and cost-effective device for data collecting with real-time thermal pictures to the ground control station (GCS), as well as the quickest medium for rapid and important agricultural analysis [5].

Unmanned Aerial Vehicles (UAVs), particularly drones, can fly autonomously with dedicated software that allows creating a flight plan and deploying the system with Global Positioning System (GPS), as well as feeding in various parameters such as speed, altitude, Region of Interest (ROI), geo-fence, and fail-safe modes [6]. Currently, low altitude aerial imagery is used to determine soil and plant characteristics in agricultural fields [7]. Drones are preferable over full-

size aircraft and satellite images for a variety of reasons, including a combination of high spatial resolution and quick turnaround capabilities, as well as low operation costs and convenience of use [8].

Drones were permitted to observe a crop field throughout the growth stages. Satellites have one or two weeks of delay before the images are available for analysis. A drone operator may operate on his own timetable and is not reliant on satellite flight paths [9].

These characteristics are critical in precision agriculture, as significant areas of land are monitored and evaluations are made in a short period of time. Aerial vehicles can be used to carry out these activities. With the miniaturization of compact cameras and other sensors connected with aerial vehicles, such as infrared and sonar, the operation becomes more sophisticated [8].

Through remotely sensed images, precision agriculture may identify principally field variability of agricultural fields owing to soil conditions and variations in crop growth development. Variations within spectral responses can be used to generate remote sensing images [6]. Drones are now capable of controlling the spread of weeds and diseases in cultivations, identifying various soil characteristics, sensing vegetation variations, and producing accurate elevation models [7].

Healthy plants, in general, reflect both green and infrared light wavebands. Sensors can monitor and identify the behavior of the reflectance pattern when plants are stressed by pests, nutrients, water or soil [8].

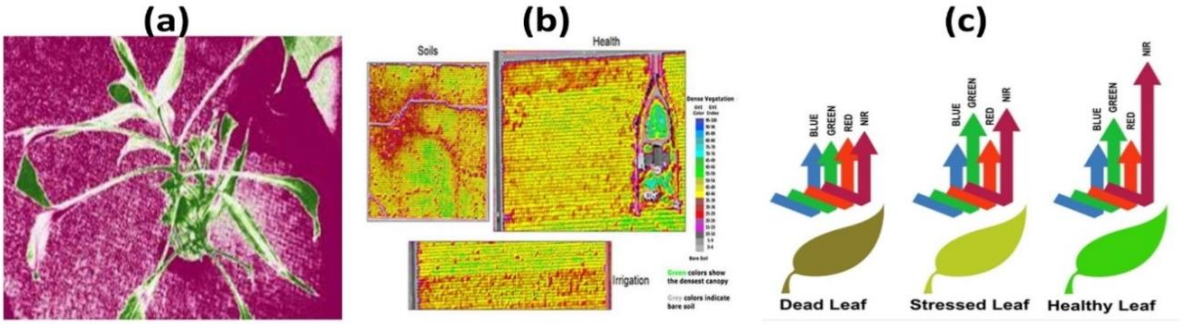


**Figure 1: (a) Output of the modified camera of a drone (NDVI image); (b) NDVI image of Sugarcane Field; and (c) NIR analysis of Leaf Area Index [23]**

Agriculturalists would monitor crops in flight and visualize patterns of irrigation-related issues, soil variance, and fungal influxes. Furthermore, crop development may be determined by comparing multiple images acquired by satellite as drones' which employ satellite remote sensing technology [10]. Aerial cameras may also be used to discover variations between distressed and healthy plants that are not visible with the human eye by collecting multispectral pictures and gathering data utilizing the optical spectrum as well as infrared [11].

Taking all of these perspectives into account, the purpose of this research is to investigate the advantages, disadvantages, possibilities, and potential implications of UAV usage in precision farming, as well as to identify future knowledge gaps. This study's specific aims were to (a) classify UAVs in agriculture based on performance characteristics, and (b) critically examine future obstacles and research possibilities that would lead to the sustainable deployment of UAVs in PA.

## 2. Methodology

According to [12], a systematic literature review procedure was used to accomplish the study's objectives since it is an accurate and reliable method. The review was conducted in 5 steps (Figure 2).

The review's key objective was to categorize UAVs in agriculture based on performance parameters utilized in recent scholarly articles, and to critically examine future obstacles and research possibilities that would lead to the sustainable deployment of UAVs in PA. We reviewed 100 publications published between 2005 and 2022 and confined our search to high-ranking journals published in English. Then, in two steps, keywords were identified: first, only the term "Unmanned Aerial Vehicles" was searched for, which should appear in titles, keywords, and/or abstracts; then, to test the search's robustness, we conducted another new search in the "Science Direct" database using the Boolean operation ("drones" OR "image processing" OR "remote sensing"; AND "agriculture"), searching in "all fields." "Articles," published between 2005 and 2022, were the category of article included in the search.

Following the elimination of duplicates in both searches, the article selection process began with multiple researchers independently reading the abstracts of the remaining articles, with the goal of only selecting articles with research questions and results directly related to the study objectives. The researchers then conducted a rigorous evaluation of the database of papers. The study focused on identifying unmanned aerial vehicles (UAVs) in precision agriculture concepts, advantages, obstacles, and critical success determinants.

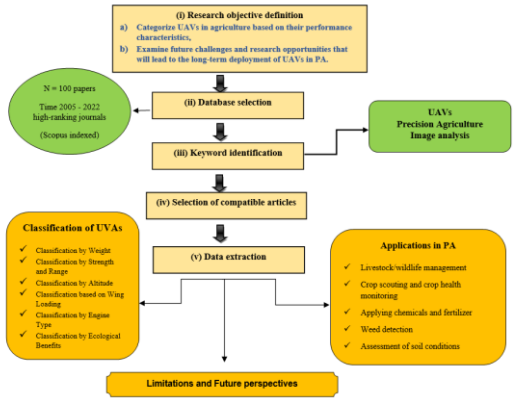


**Figure 2: Study Methodology**

## 3. Classification of UVAs

UAVs have been classified based on their various performance parameters. UAVs' major performance parameters are weight, endurance and range, altitude, wing loading, engine type, and power/thrust loading [15].

### 3.1. Classification by Weight

UAVs are available in a multitude of weights (Table 1). UAVs are classified as micro-UAVs, which weigh only a few grams, and super heavy UAVs, which weigh more than 11 tons [16].

**Table1: Classification of Unmanned Arial Vehicles (UAV) by Weight [16].**

| Type of UAV | Range of weight (kg) | Examples |
|---|---|---|
| **Super heavy** | >2000 | Global Hawk, X-45, Darkstar, Predator B |
| **Heavy** | 200 – 2000 | A-160 |
| **Medium** | 50 – 200 | Raven, Phoenix |
| **Light** | 5 – 50 | RPO Midget |
| **Micro** | <5 | Dragon Eye, FPASS, Pointer, Silent Eyes |

### 3.2. Classification by Strength and Range

Strength and range are frequently related criteria that allow the type of UAV necessary to be chosen based on the distance between the goal and the launch location. It also controls refueling time and influences how long it takes the drone to complete its mission and how long it takes to stop. According to their strength and range, UAVs are classified into three classes [16].

Type 1- The long-endurance UAVs; this type of UAV can fly for 24 hours or longer. This sort of UAV has a long range as well. Predator B and Global Hawk, for example, have ranges ranging from 1500 km to 22000 km.

Type 2- The medium-endurance UAVs: UAVs with a medium endurance can fly for 5 to 24 hours. The range of this type of UAV ranges from 100 to 400 km. This is the most popular form of UAV, such as the Silver Fox, Dark Star, Predator, and Shadow 600 [4].

Type 3- The low-endurance UAVs: This type of UAV has a flight time of less than 5 hours. This type of UAV has a range of less than 100 km. These are mostly employed for brief missions, such as Pointer [16].

### 3.3. Classification by Altitude

Another performance metric used to categorize UAVs is maximum flying height or altitude (Table 2) [16].

**Table2: Classification of Unmanned Arial Vehicles (UAV) by Altitude [16].**

| Type | Altitude (m) | Examples |
|---|---|---|
| **Low** | <1000 | Pointer, FPASS, Dragon eye |
| **Medium** | 1000 – 10000 | Finder |
| **High** | >10000 | Dark star, X-45, Predator B, Global Hawk |

### 3.4. Classification based on Wing Loading

Wing loading is another UAV performance metric that may be used to categorize UAVs (Table 3) [6].

**Table 3: Classification of Unmanned Arial Vehicles (UAV) by Wing Loading [6].**

| Type | Wing Load ($kg/m^2$) | Examples |
|---|---|---|
| **Low** | <50 | Seeker, Dragon Eye |
| **Medium** | 50 – 100 | X-45 |
| **High** | >100 | Global Hawk |

### 3.5. Classification by Engine Type

UAVs are utilized for a wide range of purposes. These activities necessitate the use of several sorts of engines. Turbofans, two-stroke, piston, rotary, turboprop, push and pull, electric, and propeller engines may all be found in UAVs (Table 4) [16]. Among the several types of engines, electric and piston engines are the most commonly employed in UAVs. Electric motors are commonly used in lighter and smaller UAVs. However, piston engines are commonly used in large and battle-ready UAVs. The kind of engine has a direct impact on a UAV's endurance and range [16].

### 3.6. Classification by Ecological Benefits

Focusing on the ecological benefits, UAVs can be classified into 4 types according to their size and power [6].

Large: This type of UAV has a 500 km operational range and a high endurance of up to 48 hours. The operational flying ceiling ranges from 3 to 20 km. Furthermore, this type of UAV, such as NASA Ikhana, can carry an extra 200kg as internal payload. Large UAVs have a number of operating limitations. The cost of acquiring, producing, and deploying this sort of platform is high, and ground operations are complicated [17]. It also necessitates significant setup and operating expenditures, ground station assistance, complete aviation clearance, a lengthy runway for takeoff and landing, and other requirements [6].

**Table 4: Classification of Unmanned Arial Vehicles (UAV) by Engine Type [6].**

| Type | Examples |
|---|---|
| **UEL Rotary** | Outrider, Shadow, Shadow 600, Cypher |
| **Turbofan** | Global Hawk, Dark star, Phoenix, X-45, X-50, Fire scout |
| **Two-Stroke** | Pioneer, RPO Midget |
| **Piston** | Predator, Neptune, Dragon Drone, Finder, A 160, GNAT, Crecerelle, Seeker, Brevel, snow Goose, Silver Fox, Heron |
| **Turboprop** | Predator B |
| **Electric** | Dragon Eye, FPASS, Dragon Warrior, Pointer, Raven, Luna, Javelin |
| **Push and pull** | Hunter |
| **Prop** | LEWK, Sperwer |

Medium: This type of UAV has a range of 500 km and a medium endurance of up to 10 hours. The operational maximum flight ceiling is less than 4 km. It can also carry a payload of 50 kg, such as NASA SIERRA. As with any big UAVs, there are operational restrictions. However, the total cost is cheaper than that of big UAVs, there are fewer takeoff and landing requirements, and it is easier to handle than large UAVs [5].

Small/Mini: This type of UAV has a range of less than 10 km and a battery life of only 2 hours. The operating flying ceiling is less than 1 km. The carrying capacity of small UAVs is 30 kg and less than 5 kg for mini-UAVs, such as the Quest UAV [4].

Micro/Nano: A type of UAV having a range of less than 10km and a battery life of only one hour. The operating flight ceiling is less than 250m. AR-drone Parrot [18] has a carrying capacity of 5 kg. Due to the high operational expenses of medium and large UAV platforms, they are unsuitable for the majority of agricultural applications. As a result, the majority of UAV applications and research activities in agriculture are presently being conducted using small, mini, micro, and Nano UAVs. It can fly autonomously, allowing it to acquire photographs with high spatial resolution. It also offers a short turnaround time, a low operational cost, and is simple to activate.

## 4. Applications in Precision Agriculture

Over the last few years, numerous scientific studies have looked into the capabilities of UAVs to provide data on a variety of precision farming applications, including livestock and wildlife management, crop monitoring, chemical and fertilizer application, weed detection, field mapping, and soil condition assessment.

### 4.1. Livestock/wildlife management – monitor the locations, status, and movement of animals over time

Traditionally, in livestock management, the locations, status, and movements of animals were determined by examining by a person [19]. Furthermore, in industrialized countries, this is accomplished by photographing from a low-flying light aircraft, which comes at a high cost. As UAVs and image analysis are used to this work, the cost will be reduced in the near future [20]. Drones offer a practical option for viewing animals from above, counting their numbers, and monitoring their movement [21]. Due to the difficulty of the human eye to see in the dark, unmanned aerial vehicles (UAVs) are beneficial for monitoring farm animals at night [22]. Drones have also been used to conduct large-animal surveys on land [5]. The majority of the research was done in Indonesia, Malaysia, Nepal, the Netherlands, and Switzerland to identify a variety of wild species in environmental studies, such as orangutans, elephants, and rhinos, in order to provide information on animal density and mobility [23]. Table 5 shows the many applications of UAV technology for livestock and wildlife management.

**Table 5: Applications of UAV in Livestock/ wildlife management**

| Application | Research description | Research highlights | References |
|---|---|---|---|
| **Wildlife Researches Species Identification** | For the inspection and supervision of livestock remotely, drones with high interpretation thermal cameras have been used. | *India has affiliated with Tata Consulting Service (TCS) to carry investigations, detect unauthorized establishments and to interfere poachers in Kaziranga National Park with 480 km$^2$ (e.g., Eudocimusalbus, Alligator Mississippiensis, Trichechusmanatus).* | [24][25] |
| | Visual observation and surveying of animals, habitat sensing, and automated telemetry tracking. | Birds, large mammalian terrestrial herbivores, and marine mammals are the most observed animals. | [26] |
| | | Using IoT and UAVs movement and habitat of wild animals that cannot be easily reached, have been observed. | [27] |
| **Cattle Herd Monitoring** | Tracking the quantity and activities of animals. | This is mostly useful in monitoring at night-time. Because humans cannot see well in the dark. | [28] |
| **Head counting** | Headcounts of cows and calves are taken by drones. | Taking headcounts of animals' innumerous classes as they are surge around the savannas. | [29] |
| **Heat detection/ Calving management** | Thermal cameras fitted in drones have been used to recognize heat signs of vulnerable one-horned rhino even if they are hiding in dense vegetation | Drones are capable of monitoring calving pastures by applying fewer burdens to the livestock. | [30] |
| **Disease Detection** | UAV centered remote sensing systems and thermal imaging were used to detect injuries in fawns in the pasture lands. | Mortality injuries of roe deer fawns (*Capreolus capreolus*) were a major problem in Israel. Because of mowing machinery and to avoid these accidents by using UAV Octocopter Falcon-8 and remote sensing analysis based on thermal imaging was hosted. | [31] |
| **Farm management** | Generating high superiority and modernized maps of huge farms using Drones. | Expansion of infrastructure, crop rotation, and grazing can be done by using Aerial maps.3D information (sward height) which was taken from the UASs has been used for meadow biomass modeling. | [32] |

### 4.2. Crop scouting and crop health monitoring

Crop scouting is an integrated pest management (IPM) method for measuring pest pressure, generally from insects, and crop growth performance. This aids in calculating the economic risk posed by insect infestations and diseases [19]. The majority of agricultural pests (fall armyworm) are more common in tropical and subtropical climates. Following infestations, fall armyworms consume mainly the juicy portions of the leaves, particularly the main midribs [8]. Because of this tendency, the leaf area of such fields decreases considerably in a shorter period of time (Figure 3). This type of destruction may be evaluated using remotely sensed high-resolution images. Infected regions should show a reduction in NIR band reflectance. In addition, the red band's reflectance should be increased due to the loss of flag leaves, exposure of the soil surface, and shadows [8].

The most common use of drones in agriculture is to inspect ongoing crops with NDVI or NIR sensors [33]. The NDVI index has been used to assess the health of green vegetation. The post-processed high-definition images enable the exposure of a larger surface area in a field in a shorter period of time, as well as the collection of data that cannot be seen by the human eye [22]. Drones capture high-resolution images of crops, and the reflected intensities of near-infrared (NIR) and visible light are compared [33]. After examining the imagery, NDVI or NIR images may be required to extract human mistakes that may exist in traditional works [2].

A Research was conducted at Virginia Tech University to detect airborne diseases using UAVs [34]. Drones gather spore samples while flying in the lower atmosphere, and the samples are examined in a laboratory. Researchers determine where the spores are moving by analyzing data and observing weather trends [34]. Table 6 indicates that different UAV applications for crop monitoring and health assessment.

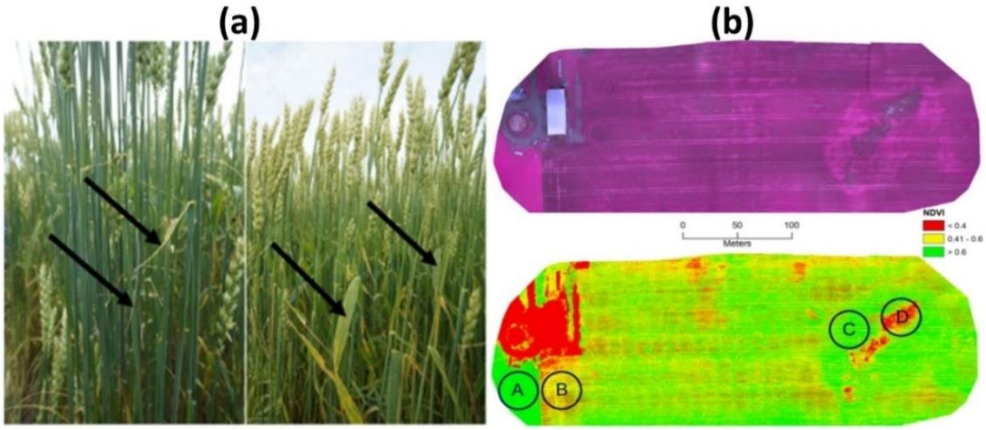


**Figure 3: (a) The difference between flag leaf of the infested (left) and healthy (right) wheat plants; and (b) Mosaicked infrared color composite map and NDVI derived map of a wheat field located in Verner on Canada**

**Table 6: Applications of UAV in crop monitoring and health assessment**

| Application | Research description | Research highlights | References |
|---|---|---|---|
| **Unsupervised detection of crops** | A study conducted on the assessment of crop characteristics of a vineyard (row height, width, spacing, and percentage of missing) by using UAV imagery analysis. | The accurate revealing of vineyards from 3D point-cloud maps, created from UAV multispectral imagery, will act a vital role, e.g., both for accomplish upgraded remotely sensed data and to handle path and process of unmanned UAV. The good accuracy obtained in ground data and UAV imagery data. | [35] |
| **To take field measurements** | A study investigated to estimate crop height, crop cover and vegetation of eight different tomato varieties in the growing season by collecting RGB and multi-spectral UAV images. | Results highlighted that height could be highly accurate and crop cover was highly correlated with field-based data. Therefore, UAV is useful for the measurements of traits such as crop height, canopy cover and NDVI throughout the growing season of a particular crop. | [36] |
| **For vegetation analysis** | VTOL quadcopter UAV is used for the applications which required a closed examination of crops such as analysis of leaf area and leaf pests. Also, fixed-wing UAVs are used for the applications which required coverage of large areas such as discrimination of crop types and counting of trees. | Spectral-spatial classification methods can be used for the mapping of crop region and tree crown with the use of images acquired by UAV. | [37] |
| **Crop mapping** | The skip maps of sugarcane fields can be created by using images taken from UAV. | The application of UAV technology has optimized the surveying of skips in fields. The object-based image analysis (OBIA) method solves complications associated with UAV images through the creation of process trees. It allows a high level of automation and adaptability. | [38] |
| | An automatic identification method was applied for tobacco fields with the use of UAV images. For the purpose, it was combined with supervised classifications methods with image morphological operations. The study was conducted in Yunnan, China. A method based on the digital mosaics based on UAV images which produced a map of gaps in a pilot study in Nicaragua. | The overall accuracy of the proposed method was 95.93%. Calculated values of real field data and derived map data for plant gaps and crop planting quality was highly correlated. | [39,40] |
| **Crop Health Monitoring** | Images acquired from Unmanned Aerial Systems were used to generate Multispectral Imaging and Elevation Mapping. Those are valuable data sources for Precision Agricultural applications. | Monitoring of crop health in mid-season. It was used NDVI maps to inspect and assess immature crops. | [30] |
| **Estimate crop emergence** | RGB images were acquired through UAVs to develop a system to estimate crop emergence of potato with the from the image analysis | This method is an efficient way to estimate crop emergence due to the results indicated higher accuracy ($r^2$ =0.96) with the comparison to manual assessment. | [41] |

 

**Table 7: Applications of UAV in chemical and fertilizer applications**

| Application | Research description | Research highlights | References |
|---|---|---|---|
| **Variable-Rate Fertility** | Fertilizer requirement could be determined by developing variable-rate application (VRA) maps from drones. | VRA maps used to determine the struggling areas which required the application of more fertilizer and healthy areas which required the application of less fertilizer. Finally, this allows decreasing the cost of fertilizer and boosting the yield. | [30,45] |
| **Crop spraying** | A research study conducted to develop a methodology to spray agrochemicals onto rice fields. | Effective Spray application pattern gives the manipulation of the flying path and swath width. UAVs could be used for successful crop spraying conditions. | [46] |
| **Crop sprayer development** | A drone-mounted sprayer developed to evaluate the field routine of groundnut and paddy crops. | This method would be useful to chemical spray for crop field areas which are not possible to spray with human interventions. | [2] |

### 4.3. Applying chemicals and fertilizer

Drones have the ability to spray insecticides, weedicides, and fertilizer to agricultural areas [42]. Spraying agrochemicals on crop fields, for example, is now done using small planes piloted by humans or by hand walking through the fields [43]. In the future, drones may be employed to spray fields [7]. Furthermore, most farmers are frequently lacking in data to determine the number of agrochemicals truly required for a crop or whether spraying is absolutely necessary [44]. Drones will not eliminate the need for chemicals, but they may reduce the quantity of chemicals used since drones can inspect crops and identify the real demand for chemicals. This might reduce production costs [23] (Table 7),

### 4.4. Weed detection

Weed maps may now be created utilizing images captured by NDVI compatible sensors and image pre-processing [19]. Farmers may readily differentiate high-intensity weed proliferation areas from healthy crop areas in agricultural fields using the data [22]. Many research studies have been conducted on the use of UAVs for agricultural monitoring in various countries across the world. Table 8 summarizes various research studies on the use of unmanned aerial vehicles (UAVs) in weed management.

**Table 8: Applications of UAV in weed detection and control**

| Application | Research description | Research highlights | References |
|---|---|---|---|
| **Invasive Species Identification** | Generate a weed map to identify invasive species (weed infestation) by using UAV image processing and NDVI sensor data. | Developed weed map that enabled farmers to separate areas with weed infestation and adjoining areas with healthy crop growth. Subsequently, it is possible for farmers to selectively spray pesticides only on areas having problems, which minimized environmental damages and cut down of costs. | [30] |
| **Crop–weed discrimination** | A model developed to detect weed in crop fields through the drone images. | The developed model has the ability to assess crop-weed discrimination in crop fields. | [47] |
| **Weed mapping** | UAV images collected to develop a weed cover map through the ortho-mosaic images over a rice field. | The proposed Fully Convolutional Network (FCN) method has high effectiveness and accuracy. Therefore, it would be used for weed mapping. | [48] |
| | A study to test the capability of UAV imagery to measure weed densities by mapping a grass weed, *Alopecurus myosuroides*, in wheat crops | Field reference and image processed weed densities were highly correlated | [49] |

### 4.5. Assessment of soil conditions

Soil maps created using high-resolution sensors may be used to detect soil types, organic matter levels, and soil moisture levels in an agricultural area [50],[7]. If this could be done with typical soil samples, a significant number of samples would be necessary to achieve the same resolution across the area. It is also time-consuming and expensive [18]. Soil conditions are extremely important for adjusting irrigation and fertilization of field conditions that rely on weather and wet areas [35]. Many research investigations indicated that UAVs would be employed for a variety of soil evaluation applications (Table 9).

**Table 9: Applications of UAVs for soil assessments**

| Research Application | Research Description | Research Highlights | References |
|---|---|---|---|
| **Soil mapping** | A novel methodology develops to determine soil sample locations by using created soil maps based on an acquisition of drone images in southern Finland. | Color maps of soil could be created for bare field plots by using UAV based imaging technology. In this study, a topsoil map was created for the objective of management of fields from ploughing to soil sample analysis. | [51] |
| **Classification of soil characteristics for ploughing** | A novel approach developed to identify different soil characteristics with different ploughing techniques by using an RGB-D sensor. | Research results revealed that the developed approach could be used to classify different ploughing depths of the fields. | [33] |
| **Volumetric assessments of soil erosion** | Research conducted to develop a methodology for volumetric asses-sments of soil erosion in rill by using UAV based images in the Central Bohemian Region. Arc GIS software was used to develop volumetric assessments of soil erosion. | A Digital Surface Model (DSM) was developed by using UAV photogrammetry for the calculations of volumetric assessment in larger areas such as; agricultural fields, catchments, or extensive gullies. | [52] |
| **Monitoring Soil Erosion** | A study conducted to develop a classification of soil eroded gullies on a large area in South Morocco by using UAV based systems. | Digital Terrain Models (DTMs) and ortho-image mosaics were created by using UAV based image processing and created models were used to monitor and quantify the gully and soil eroded lands in a large extent of fields. | [53] |
| **Determination of Soil moisture content** | A methodology developed to identify soil moisture content of topsoil by using UAV hyperspectral images in arid regions of Xinjiang, China. | High accuracy UAV images were used to develop spectral indices and prediction models. Results exhibited that pre-processed spectral indices and machine learning algorithms permit estimation of SMC precisely on the regional scale. | [54] |

## 5. Limitations

Although there is a growing interest in employing UAVs in precision agriculture, there are significant restrictions [55]. The period of data gathering in UAVs is long, and it is necessary to choose the time of day and frequency to suit. They are technically flexible, but their higher initial cost is a practical constraint for small-scale farmers [56]. Sometimes satellite data often miss important time-windows [57]. Drones used in agriculture (Nano, Mini, and Micro) cannot be used to deliver large quantities and they would carry only small amounts [43]. The main limitations of agricultural drones are their high cost, payload, and reliability for practical agricultural usage [21]. Small UAV technical restrictions include engine power limits, limited flight time, trouble maintaining flying altitude, aircraft stability, and mobility due to winds and turbulence [58].

Although the plane and the camera are inexpensive, the costs of assembly and integration of the plane are significantly higher because it necessitates the hiring of highly trained technicians and engineers. The sensor payload is limited if they employ low-cost UAVs. Furthermore, they are not as stable as high-end sensors. Because low-cost UAVs are often built with lightweight engines, their maximum flying height is limited [59]. Furthermore, it will diminish image quality, and the most significant constraint in agricultural applications is the lightweight drone payload. A UAV's payload weight restriction is typically 20–30% of the overall weight of the UAV. Payload design, as well as electrical and mechanical drone accommodation, is key elements for successful agricultural applications. Drone mishaps and component failures are driving up the price of agricultural drones and limiting their availability [21]. In addition, a drone cannot be used to collect photographs in inclement weather such as rain or strong winds. Drones can potentially be damaged by external factors like bird strikes and other unmanned aerial vehicles (UAVs) [60].

Furthermore, there are several recognized problems with utilizing cameras in drones with zoom lenses, such as limitations in optical quality, completely automated focus operations, and, most significantly, a lack of a near-infrared (NIR) band for vegetation surveys. There are small UASs with multi-spectral cameras that include the NIR band, although they are currently rather costly [61].

Because of the low flight altitudes of UAVs, significant geometric distortions can develop.

 

Furthermore, low flight altitudes produce a huge quantity of UAV images for a particular field. Furthermore, as a technical issue with recorded images, the forward-image motion of the UAV camera may result in blur. Oversampling is often used to compensate for the issue. However, it causes an increase in data volume [62].

UAV-based applications confront the same difficulties as those based on traditional aerial and satellite imaging. Equipment calibration, atmospheric error correction, line-shift correction, and band-to-band registration are only a few of the significant problems [24]. Despite the fact that precision agriculture is becoming increasingly widely used throughout the world, remote sensing applications in agriculture are still underutilized.

The regulations governing the use of UAVs are currently lacking. Flying of UAVs is also prohibited in some areas owing to security concerns. As a result, the frequency of flying UAVs must be carefully planned. The most significant barrier to the deployment of UAVs in environmental and agricultural applications is the aviation sector's regulations. These rules are relatively lax in certain nations. In Germany, for example, no authorization is necessary to operate a UAV weighing less than 5 kg, and the field must be 1.5 kilometers away from residential areas and airfields [19]. In the United States, however, each UAV flight requires a Certificate of Authorization (COA) and a substantial ground crew during the operation. In Canada, an annual Special Flight Operations Certificate (SFOC) is necessary, and some training in UAV management is strongly recommended [63]. Insurance is necessary in the case of a UAV platform failure, in addition to the certificate, because such failures may cause injury to persons, livestock, or property. Failures can occur when a UAV loses control due to a system fault or signal loss [64].

## 6. Future perspectives

Agriculture UAV applications are still in their early phases. There is much space for advancement in both UAV technology and the much potential of UAV uses in precision agriculture [64]. The enhanced mapping between UAV images and ground data, as well as the flexibility of data gathering and the relatively low cost, are the major elements that motivate others to consider UAV as a significant instrument in future precision agriculture attempts [24].

This will strengthen the integration of UAV in PA applications and consequently accelerate the evolution of technology development. The motivations for future UAV applications largely depend on the further improvements of UAV design, comparatively lower system prices, methods and procedures on enhanced image acquisition and processing, flexible regulations on agriculture and environmental applications, and availability of practical information dissemination system for farmers [66].

Furthermore, drones may be utilized to swiftly transport harvested goods from the fields to the warehouse for packing and delivery, using less fuel and people. Drones can also be utilized to transport things to the market and lower product pricing [43]. In the next years, more durable and powerful UAV platforms with advanced camera technologies such as NIR and automated geo-referencing techniques are likely to strike the market [67, 68].

Currently, many research groups and companies are working together on exploring the improvements of image pre-processing and processing which is a mandatory requirement for other applications. Most time-consuming steps are ortho-rectification and mosaicking, and new approaches that require little or no ground control are needed [69]. There are designs and development of a seeders system that is coupled with UAVs that is the spatial positioning and propulsion system. This seeder system will deposit seeds with accurate distances pre-established between plants [70,71,72]. UAVs have the potential to be a valuable tool for evaluating and monitoring rangelands and other natural resources [51]. As technology progresses and smaller and lighter multispectral and hyperspectral sensors become accessible, UAVs will become more common in natural resource applications [73].

## 7. Conclusions

UAV classification, models of agricultural UAVs, and control systems were addressed. Subsequently, agricultural UAV applications such as mapping, spraying, planting, and monitoring were reviewed and identified comprehensively. We also discussed over the constraints (such as battery life, the number of UAVs, and user interface), potential applications (such as harvesting, AI-based precise mapping, and developing countries), challenges and technological advancements in depth. Further, this research offers a glimpse at UAVs, which have a wide range of potential applications. As a result, future agricultural UAV research, markets, and applications will benefit from this study.

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# Influence of Urban Design Interventions on Outdoor Thermal Comfort in Tropical Cities; a Review

[*1]Dissanayake Clarence & [2]Weerasinghe Gamini

[*1]*Center for cities, University of Moratuwa, Katubedda, Sri Lanka*

[2]*Department of Architecture, University of Moratuwa, Katubedda, Sri Lanka*

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***Corresponding Author**
*Email:dissanayakec.21@uom.lk*

**ABSTRACT**

Comfortable urban environments attract people to public spaces. Urban designers have a great responsibility of creating thermally acceptable outdoors enhancing walkability and livability. Since intense urbanization has a harmful effect on OTC, experts tend to find strategies for urban discomfort, especially in tropics. However, transforming the current urban design into a climatic responsive design is challenging. Therefore, this paper reviews the influence of urban design interventions on OTC and concludes with the best strategies. The methodology includes two stages; bibliometric search and comprehensive content analysis which is limited to studies with physical and physiological assessments. Four components have been identified affecting OTC namely; urban surfaces, morphology, green, and blue infrastructure. Urban morphology is the most determinant component affecting OTC while green infrastructure is the most efficient method of improving comfort. Deeper canyons and compacted urban forms are more comfortable than shallow and aspersed forms. Hard surface coverage, urban form, prevailing wind conditions, morphological characteristics of tree species, and scale of open space available should be considered in vegetation inclusion. Since the material albedo and orientations of surfaces affect ambient air temperature increase, a high percentage of natural or artificial shading should be provided to adjacent hard surfaces and it helps to improve OTC irrespective of the surface material type. As a strategy, water bodies must be carefully considered in warm-humid climates and compacted urban areas. However, local climate, functionality, feasibility, and user perceptions must be considered and context-specific investigations are recommended using reliable methods such as CFD modeling prior to decision making.

## 1. Introduction

Climate change and ambient temperature increases throughout the world create outdoor thermal discomfort, thus increasing attention has been received seeking strategies to improve the urban microclimate (1; 2; 3; 4). Human population growth changes the morphology and metabolism of urban environments and accordingly alters the local climate and outdoor thermal comfort (OTC) in public spaces (5). This is an increasingly urgent area of research in tropical climates because half of the world's population lives in the tropics (6). High temperature and humidity levels in urban context result in Negative impacts on public health and productivity (7). Moreover, poor microclimatic conditions in tropical urban outdoor environments impose additional thermal stress on urbanites affecting negatively the urban ecosystem and energy use (8). OTC should be considered in urban planning due to its' significant impact on walkability, livability, and success of urban places. Freely accessible urban public spaces such as streets, parks, plazas, and squares provide spaces for urbanites to engage in recreational and other activities (9). However, improper urbanization provokes harmful influences on OTC and directly affects the perception and satisfaction of the urbanites. This poses a challenge to researchers and experts in their attempts to find appropriate methods to mitigate urban heat stress in public spaces.

Research in urban climate is gradually transformed into interdisciplinary inquiries due to the increasing engagement of architects and urban

designers (10). Sufficient empirical research has been conducted to quantify the effects of urban design parameters such as urban morphology, geometry, density, greenery (11; 12; 13; 14; 15) on OTC. Further, the effects of specific landscape elements have been investigated such as urban vegetation water bodies, and surface materials (7; 16; 17; 18) considering the urban microclimate. Moreover, (19) strongly suggested that the urban interventions should be investigated in the urban planning process since the urban design has a significant impact on microclimate and OTC (20). Further research assessing the impact of urban design parameters is essential and attention must be received in a vast range of locations and climatic conditions (2). Even though microclimate and OTC investigations have become broadly focused on different climates in recent decades (2; 3) still, contemporary urban design is in huge need of mitigating the heat stress in cities due to rapid changes in urban structure and densities (21). However, according to (22), it is still challenging to introduce a satisfactory adaptation method to improve the OTC and the knowledge is inadequate of quantitative microclimatic conditions within the urban boundary layer in the future.

A number of previous reviews have discussed mitigating strategies to improve OTC (23) thermal comfort effects of green spaces (24; 25), the impact of urban geometry (26), evaporative pavements as a mitigation strategy (27; 28), and the effects of the moderation of the components of the built environment (29). Further, (30) have reviewed outdoor thermal comfort thresholds through public space design in temperate climates. A similar review has been conducted by (31) to identify influencing factors of thermal performance for open spaces in the tropics.

OTC assessments are normally categorized into four levels namely; physical, physiological, psychological, and social behaviors (32). The interaction between the human body and the surrounding environment is included in the physical level of assessment while the physiological level comprises the thermoregulatory responses of the human body towards the thermal environment (33). This review is limited to the studies with objective assessments (level of Physical and physiological assessments) of evaluating the impact of urban design interventions on OTC focusing on the results and strategies proposed.

Although previous studies have investigated both macro and micro-scale climatic conditions, still municipal-level land use planning is critical in terms of improving context-specific environmental quality (34). Integrating the local level planning process in climatic-responsive urban design is a key to controlling the trend of urban heat in high-density tropical cities (35). It is crucial to identify proper strategies to transform current urban designs into climatic responsive designs revealing suitable methodologies, integrated tools, and improved communication among planners and climatologists (36) on a local scale. Therefore, it is important to discuss the results in previous research revealing proper strategies to improve OTC.

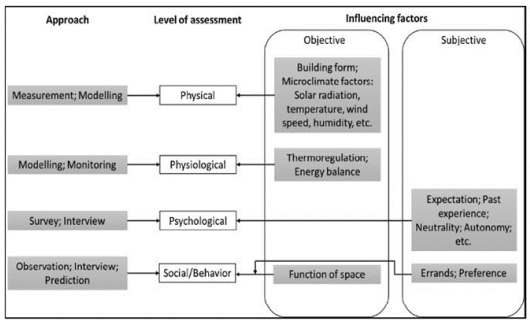


**Figure 1. A general framework for OTC assessment, Source (32)**

### 1.1. Aim of the research

This paper aims to review the studies on the influence of urban design interventions on thermal comfort in tropical cities published from 2000 to 2021 considering the studies with objective assessments (level of Physical and physiological assessments) focusing results and strategies proposed. The objectives of the study are,

i. To examine the final results in previous studies through a comprehensive literature survey.

ii. To identify the key urban design components affecting OTC and strategies to improve the thermal environment in urban public spaces through comprehensive content analysis.

## 2. Material and Methods

The methodology of this study comprises two stages; bibliometric search and comprehensive content analysis. Obtained bibliometric data from databases were filtered using the inclusion and exclusion method to finalize the articles assessing outdoor thermal comfort in urban public spaces. Then, the content analysis was conducted to examine the articles assessing the impacts of urban design parameters related to tropical cities.

### 2.1. Bibliometric search

Initial article searches were conducted based on three databases named; Scopus, Google Scholar, and Science Direct databases. The retrieval of data was performed using the keywords similar to “outdoor thermal comfort”, and “urban public spaces”. All the

 

final articles published in the English language from the year 2000 to 2021 were explored with all the information. In this stage, 738 articles were downloaded using below mentioned keywords.

### 2.2. Comprehensive content analysis

The review was divided into three consecutive stages to achieve the objectives of the study.

First, the studies with the level of Physical and physiological assessments (32) were included and subjective thermal perception-based approaches were excluded by referring to the titles and abstracts. Secondly, the studies assessing the influence of urban design interventions on OTC were included for further review. Then the urban design components and parameters were identified by referring to the abstract and the findings of selected (247) articles. Finally, the review was focused on the studies conducted in tropical climates. Then the irrelevant studies were excluded and finalized 52 articles were comprehensively reviewed to determine the design strategies proposed by referring to the entire article.

### 2.3. Scope and limitations

This study is limited to empirical studies published in peer-reviewed journals from the year 2000 to 2021 with Physical and physiological levels of assessments in available three databases. Further, only the papers which have assessed the impact of urban design parameters on OTC were considered related to tropical urban public spaces("thermal comfort" OR “thermal stress” OR “heat stress” OR “thermal discomfort” OR “outdoor thermal comfort”) AND ("urban space" OR "park" OR "open space" OR "streets" OR "public space" OR “cities” OR “squares” OR “urban” OR “public space”).

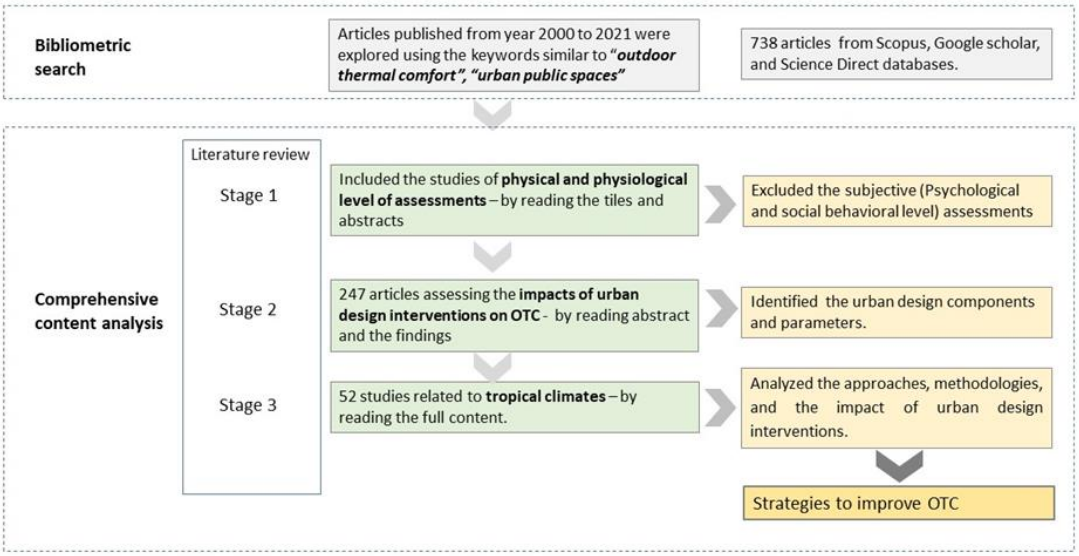


**Figure 2. Methodology flow chart**

**Table 1: key urban design parameters and the results of the final 52 articles reviewed in tropical climates**

| Source | Context | Key parameters |
|---|---|---|
| `**(37)** | Colombo, Sri Lanka | Urban morphology. Soft & hard Surfaces, land cover changes |
| **(11)** | Colombo, Sri Lanka | Urban geometry, H/W, sky view factor (SVF), orientation, ground cover, distance to sea |
| **(38)** | Colombo, Sri Lanka & Phoenix, USA | urban-area geometry, surfaces (albedo), green cover |
| **(39)** | Colombo, Sri Lanka | urban morphology; albedo, urban vegetation |
| **(40)** | Dhaka, Bangladesh | urban canyon, sky view factor (SVF), |
| **(41)** | Curitiba, Brazil | urban geometry, Sky view factor |
| **(51)** | Camagüey, Cuba | height-to-width ratio, street axis orientations (N-S, NE-SW, E-W, SE-NW), Asymmetrical street aspect ratios |
| **(52)** | Tainan, Taiwan | Vegetation, tree location, shading |
| **(53)** | Constantine City, Algeria | SVF, H/W ratio and presence of trees |
| **(54)** | Ternate City, Indonesia | space configuration |
| **(70)** | a residential district in Iran | Urban greening, Trees design, Urban microclimate, UHI mitigation, ENVI-met |
| **(71)** | Zabol, Iran | Vegetation, green space structure |

| | | |
|---|---|---|
| **(17)** | Negev Highlands of southern Israel | Landscape elements (trees, grass and mesh) - water use - Shading - Surfaces coverage ratio |
| **(42)** | Huwei Township, Taiwan | Sky view factor |
| **(43)** | Bandar Abbas, Iran | urban morphology |
| **(44)** | Dar es Salaam, Tanzania | urban morphology |
| **(12)** | Damascus, Syria | Vegetation, Urban morphology |
| **(45)** | Aleppo, Syria | Urban Geometry, aspect ratio (H/W) and low sky view factor (SVF) |
| **(46)** | Singapore. | Urban Geometry |
| **(47)** | Sao Paulo, Brazil | Built density<br>Urban vegetation |
| **(48)** | Campinas, Brazil | Trunk geometry - Crown geometry - Tree height - Permeability -Leaves type - Leaves shape - Individual or cluster planting |
| **(49)** | Generic urban canyon | aspect ratio (ARB) with embedded trees of varying aspect ratio (ART), leaf area index (LAI), leaf area density (LAD) |
| **(50)** | Putrajaya city, Malaysia | SVF of urban streets |
| **(7)** | Singapore. | pavement materials, greenery, and water bodies |
| **(66)** | Southern China | Canyon aspect ratio (CHW), the canyon axis orientation, arcade proportion (AHW), and the tree-covered area (TCA). |
| **(67)** | city of Isfahan, Iran | Sky view factor, Street orientations, Type of greenery, greenery arrangement |
| **(68)** | Kuala Lumpur, Malaysia. | Trees, and Road Orientation, Sky view factor |
| **(36)** | Campinas, S~aoPaulo, Brazil | Building height , Canyon orientation, Aspect ratio (H/W)Mean building height, pavement material |
| **(69)** | Iranian climate types | Urban Morphology, Sky view factor, Shade coverage, Vegetation and water, Street aspect ratio, Reflectivity, Traffic density, Metabolism clothing. |
| **(72)** | Dubai-UAE | Urban geometry or buildings configuration |
| **(55)** | Penang, Malaysia | Shade tree, Reflective Pavement |
| **(56)** | Kowloon bay area, Hong Kong | Tree-planting, Tree species Street-canyon, Urban densities |
| **(57)** | Guangzhou, China | Street canyon design -aspect ratio, street orientation, street orientation, surface materials |
| **(58)** | City University of Hong Kong | Leaf area index - Trees canopy density – Waterbody |
| **(59)** | Beijing, China | Grass - Tree - Hardened ground - Waterbody – Building |
| **(60)** | Matara, Sri Lanka | Green infrastructure - Vertical and horizontal green surfaces. |
| **(61)** | Delft University, Netherlands | Surface albedo, position and orientation (Roof and wall) of albedo materials |
| **(20)** | Dar es Salaam, Tanzania | built-up areas with different morphologies including low-, medium-, and high-rise buildings |
| **(62)** | Phoenix, USA | tree location, tree layouts, tree species |
| **(63)** | Adana, Turkey | Tree crown density - Planting density |
| **(64)** | Hong Kong | The height of the tree - Trunk height - Crown height - Crown diameter width - Leaf area index |
| **(3)** | Concepción, Chile | sky view factor, shadow factor of buildings |
| **(65)** | Rajarhat Newtown, India | Urban geometry<br>Street orientation<br>Canyon aspect ratio |
| **(18)** | Malacca Town, Malaysia | Pavement material, waterbody, |
| **(73)** | Guangzhou, China | Green-blue-grey infrastructures |
| **(16)** | Netherlands | Urban water bodies |
| **(15)** | New Aswan city, Egypt | Urban geometry |
| **(8)** | Bihar, India | Vegetation, Morphology and wind |
| **(74)** | Hong Kong | Greenery, Urban densities |
| **(75)** | Singapore | Vegetation |
| **(76)** | Singapore | Urban geometry- street orientations, street aspect ratios |
| **(4)** | Hong Kong | Water Spraying systems, Blue technology |

## 3. Results and Discussion - studies assessing the OTC in public spaces in tropics

The results of the comprehensive content analysis (52 journal articles) explored the OTC improvement strategies in tropical climates. Table 1 presents the urban context and key urban design parameters assessed in empirical studies in chronological order from 2005 to 2021. The results of the particular studies help to identify the most influential urban design components and parameters. The cooling effects of different parameters related to different urban design components are discussed and the strategies are proposed in the next sections referring to specific results and cooling benefits achieved in the empirical studies reviewed.

### 3.1. Main components affecting OTC in Urban spaces

Urban planners, landscape architects, and environmental policymakers have involved and implemented several modifications of the built environment with alteration of surface materials, urban morphology, irrigation systems, and greenery for facilitating urbanites (49). According to the review of (23), altering urban geometry, planting vegetation, using cool surfaces, and incorporating water bodies have been identified as four major mitigation strategies to improve OTC in urban areas. There are five urban interventions effect for cooling the urban outdoors called; shading elements, building arrangement with wind movement, cool surface materials, water sink techniques, and tree planting and vegetation (29). Moreover, (22) has argued that building disposition, vegetation arrangement, shading elements, and water spraying systems should be considered in improving OTC at the pedestrian level. Nevertheless, (12) have argued that three factors are of dominant importance and affect the thermal comfort level, namely, urban space morphology, the orientation of elements and spaces, and vegetation in designing urban spaces.

However, the urban surfaces also affect massively on the OTC levels. OTC at the pedestrian level is highly affected by the location and the orientation of the urban surfaces due to specific albedo values and reflected directions in urban open spaces (28; 77). Moreover, urban geometry and construction materials (78) and material properties affect the energy balance of surfaces (79). Furthermore, the surface energy balance is affected by urban hydrological processes such as runoff, infiltration, interception, or irrigation of the urban areas and especially improve the OTC level during heatwave conditions, even though, it increases the humidity (80; 22). Further, studies of blue technology have received the lowest attention as a strategy for improving the OTC and climate-responsive urban design (22). Additionally, implementation of the cooling strategies depend on the surrounding characteristics of the urban space as highlighted by (23), thus the cooling effect of vegetation, cool surface, and water bodies are lower in compacted urban space comparing to an open area. Although the water bodies are quite neglected in OTC assessments, the influence is considerable, especially in hot dry climates. As a result of the review, it is understood that there are four urban design components affecting OTC in public spaces namely; thermal properties of urban surfaces, Morphology and geometry, green infrastructure, and blue infrastructure. Table 2 presents the main urban design component and the relevant parameters assessed in previous research.

**Table 2: urban design components and related parameters assessed in previous studies tropical urban public spaces**

| Urban design component | Parameters investigated |
|---|---|
| Urban surfaces | Albedo |
| Green infrastructure | Plant area index (PAI), Location of trees, Leaf area density (LAD), The aspect ratio of trees (ART), Canopy cover, Vegetation density, Planting patterns and arrangement, Grass coverage, Tree species, facade greening, Tree type, Canopy form. |
| Morphology and geometry | Sky view factor (SVF), Street ratio H/W, Street axis orientations, Building height, Building orientations, Building density, Urban density and compactness, Spaces between buildings. |
| Blue infrastructure | Depth and size of the water body, Character (dynamic or still), Location of the water body. |

### 3.2. Influence of urban design interventions on OTC

- **Urban surfaces**

The thermal properties of urban surfaces should be carefully considered in urban design practices. The high duration of heat hours creates heat stress in tropical cities during the daytime due to the high percentage of hard surface coverage. The urban bio-climate changes are strongest when ‘‘hard’’ land cover increases significantly (37). Among the thermal properties of surfaces, the albedo (percentage of reflected solar radiation from a surface) has been widely considered and proven as an influential factor in urban climatology.

Therefore, assessing the impact of surface albedo has received considerable research attention and has empirically assessed the influence of both

 

dark (low albedo) and light color (high albedo) materials. Although high albedo materials are an effective strategy to reduce pedestrian thermal discomfort (81), recent empirical studies have revealed that the high albedo materials affect negatively on ambient air temperature due to high reflected solar radiation (78). However, Thermal comfort at the pedestrian level is further weakened by high albedo materials due to the heat waves (82). Moreover, the Orientation of the urban facades alters the OTC level and the raise of the material albedo of vertical surfaces shows a linear increase in the heat stress at the pedestrian level (77). Whilst, (83) and (84) argue that increased solar reflectance of materials (high albedo) shows a considerable reduction of the surface temperature and it helps to reduce the convection of heat from the material surface to the ambient temperature. Conversely, Surfaces with low albedos (high reflective materials) create longer hot hours in day time compared to high albedo ones (85) and increase the re-radiation (61). Therefore, selecting proper urban surface materials with proper albedo values and orientations of vertical and horizontal surfaces is critical. The reason is the law albedo materials increase the surface temperature while the high albedo materials increase the ambient temperature due to high reflected radiation, which leads to thermal discomfort. However, (86) has concluded that, when considering the short-term urban redevelopments, the promotion of urban surface material is more feasible, and cool building/surface material should be provided in further policy analysis.

- **Urban morphology and geometry**

Urban microclimate and OTC is affected due to the altered duration of incoming solar radiation and the mean radiant temperature (MRT) which creates by various urban forms (1). Some research has investigated the individual parameters of elements in urban areas such as building density and height of buildings (14). But in recent years combined parameters that create different urban forms have been considered, such as height/width (H/W) ratio, sky view factor (SVF), and the orientation defined by its long axis. These are the determinant factors of urban geometry (87) and directly influence the transformation of incoming solar radiation into outgoing longwave radiation. This phenomenon significantly impacts the temperature variations in the surrounding environment which is called the urban heat island effect (88; 89; 90).

The aspect ratio describes the building height (H) to road width (W) ratio. In a street canyon, aspect ratio and orientation are the parameters that control the solar access which affect the OTC inside (87). According to the results of previous research in the tropical regions, an increased (H/W) ratio gives more significant cooling benefits (56; 87), due to the shade within deeper canyons (38). Moreover, the canyons with higher H/W aspect ratios increase wind velocity and shading by improving thermal comfort at the pedestrian level. Nevertheless, the street length to building height (L/H) ratio had no significant effect on the thermal comfort level at the pedestrian level (36).

The sky view factor (SVF) has been widely assessed and revealed as an essential parameter for assessing urban microclimate. SVF is defined as the fraction of sky visible from a certain point in the street canyon, while the aspect ratio (AR) is the height of the adjacent buildings divided by the street width, which is also called the H/W ratio. The relationship between these two is the lower sky view factor means a higher aspect ratio and vice-versa (56). According to (91), in urban street planning, SVF and the position of the visible sky regarding the sun path and the cardinal directions should be considered to better understand the resultant micrometeorological and human thermal comfort conditions. In urban heat island mitigation, geometry plays a vital role, and the lower sky view factors increase the OTC and ambient air temperature (86). SVF should be considered in urban design evaluation and decision-making process as a key geometry parameter of urban design (88).

Previous research analysis demonstrated that orientation and aspect ratio strongly affect the magnitude and duration of the thermal peaks at the pedestrian level (90). Further, (68) has revealed that the North-South (N–S) and Northeast–Southwest (NE–SW) orientated roads are better than the East-West (E–W) and Northwest–Southeast (NW–SE) axis in terms of OTC enhancement. Since tall buildings improve wind flow and obstruct solar access, asymmetrical street canyons are more suitable in terms of OTC enhancement than symmetrical streets with low buildings (50). Further, the highest comfort reduction has been observed in north-south oriented streets with tall buildings of about 100m and this creates additional shade for adjacent parks or public spaces nearby increasing comfort conditions (44).

- **Green infrastructure**

Green infrastructure improves the microclimate by reducing hot air flows, evapotranspiration, and shading as the most efficient way to reduce the negative effect of warming urban environments (92). For the moderation of negative impacts of the UHI effect, vegetation is the most commonly used method (93). Providing visual aesthetics for pedestrians, urban greenery accomplishes beneficial microclimatic effects, including air temperature reduction, which cures the UHI effect, provides shading, improved air quality, and reduces noise levels (94). Further, (28) has concluded that

"vegetation is a better choice for improving thermal comfort in the pedestrian level" as tropical countries receive more intense solar radiation. The highest impact of green space on the physiologically equivalent temperature (PET) index is related to air temperature and mean radiant temperature (71). The cooling effect of vegetation depends on urban configuration, soil temperature and humidity, leaf area index, and green distribution. As an example, in a compacted grid urban morphology, dense trees along the sidewalk is the best for improving OTC, compared with a central park and pocket parks, as concluded by Duarte et al. (47).

A larger tree-covered area (TCA) ensures improved OTC, the magnitude varies with the tree-planting pattern (49). Trees are the most effective factor for reducing long-wave radiation exchange by blocking short-wave radiation penetration to the surface compared to ground covers since turf lawns and shrubs only provide surface shading (17). Further, as mentioned by (95), roof greening is not effective for human thermal comfort near the ground level, but trees are suggested to be more effective than grass surfaces in cooling pedestrian areas. Although the shadow and wind patterns have less impact on the OTC in large open spaces, those factors are quite important for smaller spaces near the buildings (57). Green areas have a pronounced cooling effect and reduce the ambient outdoor temperature with increased canopy densities and tree coverage densities in urban areas (55). 60% of temperature reduction is provided by the foliage density as the most efficient factor, even though other morphological characteristics of trees such as tree height, trunk height, and crown diameter are determinants (64). Thus, trees with high foliage density have high heat mitigation capacity and vice-versa for trees with low foliage density. However, heat reduction capacity can be restricted depending on the location (96).

According to (97), the effective management of trees and higher densities affect improving thermal comfort. Isolated trees are found to provide better cooling than loosely clustered ones, containing open spaces in between (8). The OTC benefits of trees are also responsive to Leaf area density (LAD) distributed across the different heights of the tree besides the LAI value while the trunk height seems to be the least important factor (56). However, the trunk height has a stronger effect than foliage density and tree height to obtain the ventilation impact (64). Canopy-size/ cluster-density at lower wind speeds directly affects the reduction of PET value and vice versa at high wind speeds (8). Moreover, high crown and plantation density is preferable for daytime, and inversely for nighttime, regardless of the crown density, since it does not affect wind speed and direction (63).

According to all the results reviewed, to maximize the comfort benefits, the tree location and arrangement should be carefully considered. The type of green infrastructure depends on the scale of open space available and the function of the space. The pattern of tree planting is defined by the urban morphology and the amount of solar radiation to be reduced. The selection of ideal tree species seems to be the most significant factor since it covers several determinant factors of cooling benefits such as morphological characteristics of trees. Therefore, from an urban design perspective, vegetation configuration in urban areas is essential considering hard surface coverage, urban form, prevailing wind conditions, morphological characteristics of tree species, the scale of open space available, seasonal climate conditions, and day and night time climate differences.

- **Blue infrastructure**

Water is also an urban surface, which is cooler than hard pavements due to its' low reflectivity and high thermal inertia (78). Although the water surfaces act in a positive way in the urban thermal process with the evaporative cooling effect, blue infrastructure has received the lowest attention as a strategy for improving the OTC and climate-responsive urban design (22). In hot dry climates, the use of water features in urban areas is a good heat reduction technique to improve the pedestrian thermal comfort level, but the water features would not act similarly in heat reduction for climates with high humidity conditions (29). Therefore, this should be confirmed in future research and have to identify specific strategies to design urban spaces with water bodies to achieve desirable OTC levels. According to the empirical evidence, the cooling effect of water bodies is less in compact urban spaces than in open areas same as vegetation and cool surface (23). Recently (22) have found that the water spraying systems offer a 2-3 0C cooling effect for the ambient air temperature at the pedestrian level of the urban canyons. However, the PET reduction provided by water surfaces is less than vegetation (98). Nevertheless, (59) concluded that there is no statistical correlation between the water bodies and thermal comfort sensation, but it can moderate the subjective sensation of the visitors could be moderated by providing fine scenery.

Though many researchers have proposed different mitigation measures on various scales for microclimatic improvements, the efficiency is still subject to argument. The reason is the microclimate is very significant due to local climate effects.

## 4. Conclusion

This paper reviewed the empirical studies on the impacts of urban design interventions on thermal comfort in tropical cities published in peer-reviewed journals in the last two decades, with objective assessments (level of Physical and physiological assessments). The methodology includes two stages; bibliometric search and comprehensive content analysis. Bibliometric data were limited to three databases and filtered using the inclusion and exclusion method. The analysis was focused to examine the approaches, methodologies, and final results in selected 52 articles focusing on strategies for improving the OTC in tropical urban spaces.

Comfortable urban environments attract people to public spaces and urban designers have a great responsibility of creating thermally acceptable outdoors. The identified main determinant factors of OTC are highly recommended to consider in urban planning. Therefore following conclusions could be made through a literature review related to thermal properties of urban surfaces, morphology and geometry, green infrastructure, and blue infrastructure.

Selecting proper urban surface materials with proper albedo values and orientations of vertical and horizontal surfaces is critical. The reason is the law albedo materials increase the surface temperature while the high albedo materials increase the ambient temperature due to high reflected radiation, which leads to thermal discomfort at the pedestrian level. However, cool surface material should be provided in further policy analysis as the empirical studies have proven yet. The orientation of the urban facades alters the OTC level and the high albedo of vertical surfaces creates heat stress at the pedestrian level. Further, providing a high percentage of shaded area (natural or artificial) to the hard surface gives more comfort irrespective of the surface material.

Urban morphology and geometry have received the highest attention as the most determinant component affecting OTC. Urban form alters the duration and amount of transforming incoming solar radiation into outgoing longwave radiation. Generally, deeper canyons and compacted urban forms are preferable in tropical climatic conditions due to increased wind velocity and shading compared to shallow and sparse urban forms. Although the street length to building height has no effect on OTC, the orientation of streets has a significant effect and N-S oriented streets are better than the E-W streets. The SVF and the position of the visible sky regarding the sun path and the cardinal directions should be considered in urban planning.

Green infrastructure is the most commonly used and efficient method to improve OTC. It reduces long-wave radiation exchange by blocking short-wave radiation penetration. The selection of the type of green infrastructure depends on the scale of open space available and the function of the space. The pattern of the tree planting is defined by the urban morphology and the amount of solar radiation to be reduced. The selection of ideal tree species could be the most significant factor since it covers several determinant factors of cooling benefits such as morphological characteristics of trees. Therefore, from an urban design perspective, vegetation configuration in urban areas is essential considering hard surface coverage, urban form, prevailing wind conditions, morphological characteristics of tree species, the scale of open space available, seasonal climate conditions, and day and night time climate conditions.

Comfort improvement provided by blue infrastructure is less than vegetation and urban morphology. It has received the lowest attention as a strategy for improving the OTC. Even though, the water features would not be a good heat reduction strategy in humid conditions, it is a good heat sink technique for hot dry climates. Water bodies are preferable in open areas to achieve OTC, but not for compacted areas. However, it could affect the subjective sensation of the visitors by providing fine sceneries.

Though many researchers have proposed different mitigation measures on various scales for microclimatic improvements, the efficiency is still subject to argument. These strategies could not be directly applied without considering the local climate, functionality, feasibility, and user perceptions. The reason is that the microclimate is very unique to the local climate. Therefore, context-specific investigations are recommended using reliable techniques such as computational fluid dynamics (CFD) modeling prior to urban design decision-making.

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# Blue Carbon Stocks; Distribution, Threats, and Conservation in Sri Lanka; Insight Towards Climate Change Mitigation

[#1]Gunathilaka DUV, [#1]Wijesundara WMIC, [1]Abeysinghe NK, [1]Ranawaka DPD, [2]De Silva PMCS, [3]Madarasinghe SK, [1]Wijerathna GGNK, [1]Jayatissa LP, [4]Andrieu J & [*1]Kodikara KAS

[1]*Department of Botany, Faculty of Science, University of Ruhuna, Matara, Sri Lanka*

[2]*Department of Zoology, Faculty of Science, University of Ruhuna, Matara, Sri Lanka*

[3]*Department of Physics, Faculty of Science, University of Ruhuna, Matara, Sri Lanka*

[4]*GEOspatial Monitoring and Information Technology (GeoSMIT) Department, French Institute of Pondicherry (IFP), Pondicherry, 605001, India*

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**[*]Corresponding Author**
*Email:sunandaruh@gmail.com*
***[#]First Co-authors***

**ABSTRACT**

As a tropical island nation, Sri Lanka has a 1740 km coastal strip, dominated by mangroves, salt marshes and seagrass meadows i.e., blue carbon ecosystems, that play a vital role in ecosystem functioning and services. These ecosystems have a high capacity for storing carbon within their ecosystem pools by capturing atmospheric carbon dioxide ($CO_2$) through photosynthesis and gained huge attention as the most carbon rich soil containing ecosystems in the world. The current study focuses on the gaps pertaining to blue carbon ecosystems including, total carbon stocks, challenges, and conservation prospects in Sri Lanka. Accordingly, a complete scientific survey to determine carbon stocks in all blue carbon ecosystems has not been carried out and only a limited number of studies have quantified the carbon sequestration in different mangrove areas in Sri Lanka. Studies on salt marshes and seagrass meadows were only directed towards distribution, species diversity or occurrence and also limited to fewer sites in the country. Thus, precise estimation of the total carbon stocks of the blue carbon ecosystems would be difficult without conducting proper scientific studies in salt marshes, seagrass meadows and mangrove areas. Moreover, the current study suggests seeking knowledge through estimating ecosystem values towards sustainable coastal management that could pave the pathway to conserve blue carbon ecosystems as a part of climate change mitigation.

## 1. Introduction

The rapid increment of the emission of carbon and other greenhouse gasses play a dominant role in global warming and subsequent associated environmental crises. Human activities have unequivocally caused crucial environmental issues since pre-industrial period and have been driving it to an alarming rate in recent years [4]. The scientific community has revealed that a new high record was reported for the global average atmospheric carbon dioxide which was 409.8 ± 0.1 ppm (parts per million) in 2019 reaching the highest level in the past 800,000 years. In the 1960s, the annual rate of global atmospheric carbon dioxide growth was approximately 0.6 ± 0.1 ppm whereas in 2018 the increment was reported as 2.5 ± 0.1 [32]. Anthropogenic emission of carbon dioxide through burning fossil energy, industrial production, forest fires, deterioration and deforestation of natural vegetation and ecosystems of natural carbon sinks majorly contribute to the rapid increment of atmospheric carbon dioxide [39].

In the future, the increased rate of atmospheric carbon dioxide concentrations will mainly depend on human activities and the interactions of the natural carbon sinks [59]. Ocean ecosystems have been recorded as the largest natural carbon sink on earth which absorbs and fix one third of the anthropogenic carbon dioxide emissions in the atmosphere, whereas terrestrial ecosystems sequester atmospheric carbon dioxide in soil and plant biomass through photosynthesis [18, 55]. Cyclically, carbon is released back to the atmosphere as carbon dioxide or methane through anaerobic respiration and

decomposition of dead biomass [4]. However, recent studies have highlighted that both efficiencies of carbon dioxide sequestration and longevity (centuries to millennia) of the sequestered carbon sinks of coastal wetland ecosystems are higher than tropical, boreal and temperate forest ecosystems resulting in extensive carbon stocks [4, 43]. Tropical forests, temperate forests, boreal forests and tropical savannas are considered as important terrestrial ecosystems and each ecosystem stores less than 400 Mg C $ha^{-1}$[26].

## 2. Blue carbon ecosystems

Coastal wetland ecosystems, are dominated by mangroves, tidal marshes and seagrass meadows [7]. The carbon sequestered and stored within the aboveground living biomass (branches, stems and leaves), belowground living biomass (roots) and nonliving biomass (deadwood and litter) and soil or underlying sediments of the mangroves, tidal salt marshes and seagrass meadows is called as blue carbon [19]. The soil or the sediments in blue carbon ecosystems are saturated with continuous waterlogging, anaerobic condition and high rates of vertical accretion giving rise to increased carbon pools over time [9]. Unlike terrestrial soil, however, soils in blue carbon ecosystems have a high potential in soil carbon accumulation due to low oxygen availability. These conditions allow reducing aerobic microbial carbon oxidation releasing carbon dioxide back into the atmosphere [57]. Given that, the blue carbon is sequestered in living biomass for a short term (decennia) while longer terms (millennia) in the soil [34]. Furthermore, in a global context, blue carbon ecosystems coverage accounts for 51 million hectares, of which mangroves solely account for 31%, (15.6 million hectares). Interestingly, even though, only 0.2% of the oceanic ecosystem consists of blue carbon ecosystems, approximately, 50% of the total marine sediment carbon deposits consist of coastal wetland sediment carbon deposits [37].

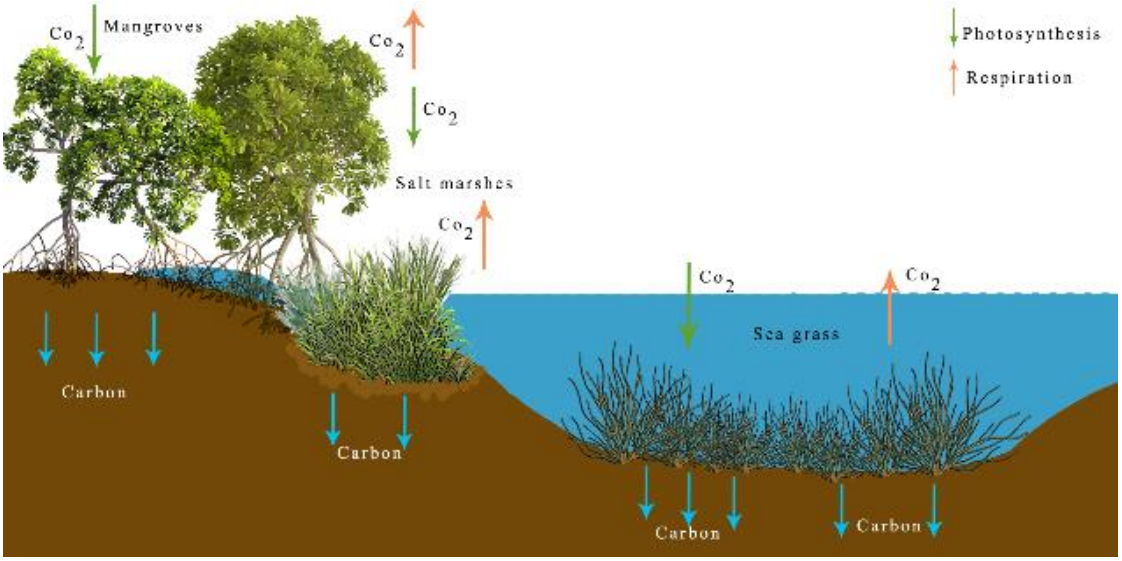


**Figure 1: A typical illustration of the fate of carbon dioxide in blue carbon ecosystems (Source: Concept adapted from Arulnayagam and Park, 2019 and illustrated by D.P.D. Ranawaka)**

Mangroves, the tidal forests, are unique plant communities that grow in extreme environmental conditions such as high and fluctuating salinity, extreme tides, frequent inundation with associated hypoxia, low air humidity and high temperatures. Predominantly living at the interfaces in the land and sea in tropical and subtropical coasts, mangrove ecosystems are rich in blue carbon [31, 61]. Recent studies revealed that approximately 24 Tg C $yr^{-1}$ has been captured by mangroves globally as well as accumulated approximately 6.5 Pg C (petagrams of carbon) [7, 47]. Total ecosystem carbon stock of mangroves was reported to ranging from 154 to 1484 Mg C $ha^{-1}$ with a mean global carbon stock of 885 Mg C $ha^{-1}$ from an estimated global mangrove coverage of 13.8 – 15.5 million hectares [10,15, 27]. 20% of the mangrove blue carbon is stored in the living biomass of the trees (roots and shoots) whereas, 2% is in downed wood and a prominent proportion of 78% in soil due to a tendency of relatively rapid accumulation [1, 2].

Tidal marshes are biodiversity-rich, unique ecosystems located at the interface between marine and terrestrial ecosystems connecting freshwater and saline ecosystems. Tidal marshes occur in all regions except extreme regions like Antarctica, particularly in temperate areas in high to middle latitudes, and are commonly restricted to sheltered locations [42]. According to the spatial data obtained from UNEP-WCMC (United Nations Environment Programme-World Conservation Monitoring Centre) in 2005, global tidal marsh covers range from 2.2 – 40 M ha with a central estimate of 5.1 M ha. These communities consist of upper, vegetated mudflats

 

lying in the mean high intertidal areas and layers of deep mud and peat. In addition, the salt marsh vegetation, the carbon sequestering biomass comprises of halophytic low shrubs and grasses influenced by zonation patterns and tidal immersions. Further, the rapid colonization of sediments enhances the vertical expansion and horizontal spreading of the salt marshes over time contributing as an important carbon sink [54]. Comparatively, tidal marshes store moderate to high carbon stock than other blue carbon systems yet participate in low carbon dioxide emissions due to their relatively small global area coverage. The literature states that tidal marshes store 237-949 Mg $CO_2$ $ha^{-1}$ (approximately 593 Mg $CO_2$ $ha^{-1}$) of near surface carbon stocks (cumulatively, biomass and top meter sediment) and emit 0.02 – 0.24 Pg $CO_2$ $yr^{-1}$ (0.06 Pg $CO_2$ $yr^{-1}$) of carbon dioxide to the atmosphere [48].

Seagrass meadows are a unique group of underwater angiosperms occurring in shallow oceanic and estuarine waters across 191 countries and six bioregions spanning temperate and tropical seas [58]. The spatial distribution estimates of seagrass meadows differ throughout literature due to their static nature and lack of mapping data [40]. However, according to UNEP-WCMC spatial data in 2005 globally, seagrass meadows range from 17.7 to 60 M ha with a central estimate of 30 M ha. Seagrass meadows depend on the penetrating sunlight for photosynthesis thus, distributed 10 – 15 m depth in turbid shallow coastal waters or sometimes up to 50 m depth in less turbid waters. Blue carbon is trapped in the living biomass (leaves, fruits, flowers and seeds) and sediments [46]. Seagrass meadows estimate to store 131 – 522 Mg $CO_2$ $ha^{-1}$ (326 Mg $CO_2$ $ha^{-1}$) and emit 0.05 – 0.33 Pg $CO_2$ $yr^{-1}$ (0.15 Pg $CO_2$ $yr^{-1}$) [48].

The anaerobic nature of the soil blue carbon ecosystems causes prolonged decomposition rates of litter and dead biomass trapping and preserving soil organic carbon pools for centuries. Surprisingly, even the lower primary production outweighs the slow decomposition rates [56]. Thus, these substantial amounts of stored carbon sinks weigh the danger of being released proving the enhanced climate mitigation strategies of blue carbon ecosystems [11]. Additionally, towards the impacts of global warming such as sea level rises and increased storms, these ecosystems act as a natural buffer of waves against storm surges, tsunamis and floods [41]. Moreover, quantification of carbon stocks in blue carbon ecosystems should be taken into high priority concerns to get a wide understanding of climate change mitigation.

Therefore, this paper attempts to seek three major research questions; a) What is the state in the literature of coastal blue carbon ecosystems in Sri Lanka b) amounts of below ground and above ground blue carbon stocks in Sri Lanka c) challenges for effective conservation and prospects of blue carbon ecosystems in Sri Lanka and stating some of the knowledge gaps that could support to understand blue carbon dynamics in Sri Lanka which could pave the path to policymaking and climate change mitigation.

## 3. Blue carbon in Sri Lanka

Sri Lanka is a tropical, island country, located in South Asia, surrounded by the Indian ocean ($5.55^0$ - $9.51^0$ N and $079.41^0$ - $081.54^0$ E.), with a total land extent of 65,610 $km^2$ and a coastal strip of 1,740 km [10]. According to the Coast Conservation Act No. 57 of 1981 in Sri Lanka, the demarcation of a coastal zone describes as “the area lying within a limit of 300 m landward of the mean high-water level and a limit of 2 km seaward of the mean low water level. In the case of rivers, streams, lagoons or any other body of water connected to the sea either permanently or periodically, the landward boundary extends to a limit of 2 km measured perpendicular to the straight baseline drawn between the natural entrance points. Thereof and includes the waters of such rivers, streams and lagoons or any other body of water so connected to the sea”. Sri Lankan coastline consists of blue carbon ecosystems predominating by mangrove ecosystems. The total mangrove coverage of the island accounts for approximately 8000 ha [29]. However, Premakantha et al. (2021) have reported the mangrove extent in Sri Lanka to be 19,758 ha. Micro-tidal conditions along with coastal topography restrict mangrove areas into narrow strips along the coast, except in the estuaries of larger rivers [65]. Tidal marshes distribute across 23,819 ha on the southern, western, northern and eastern coasts of Sri Lanka [46]. Seagrass meadows extensively existed on the northern, northwestern, northeastern coasts of Sri Lanka while they occur to a lesser extent on the southern, southwestern and southeastern coasts, covering approximately 37,137 ha [62]. Even though Sri Lanka is rich in mangrove species diversity with 21 true mangrove species [21], only a limited number of studies have quantified the carbon profiles in these ecosystems (Figure 2) [10, 22, 50, 51, 52], Similarly, for tidal salt marshes and seagrass meadows, studies were only directed towards distribution, species diversity or occurrence and restricted to a limited number of sites in the country [46, 62].

A study carried out by Perera & Amarasinghe (2019) has quantified the soil carbon content in seven mangrove sites; Negombo, Kala Oya (river) estuary, Malwathu Oya estuary, Chilaw lagoon, Rekawa lagoon, Batticaloa lagoon and Uppar lagoons that cover dry, intermediate and wet zones in Sri Lanka [51].

 

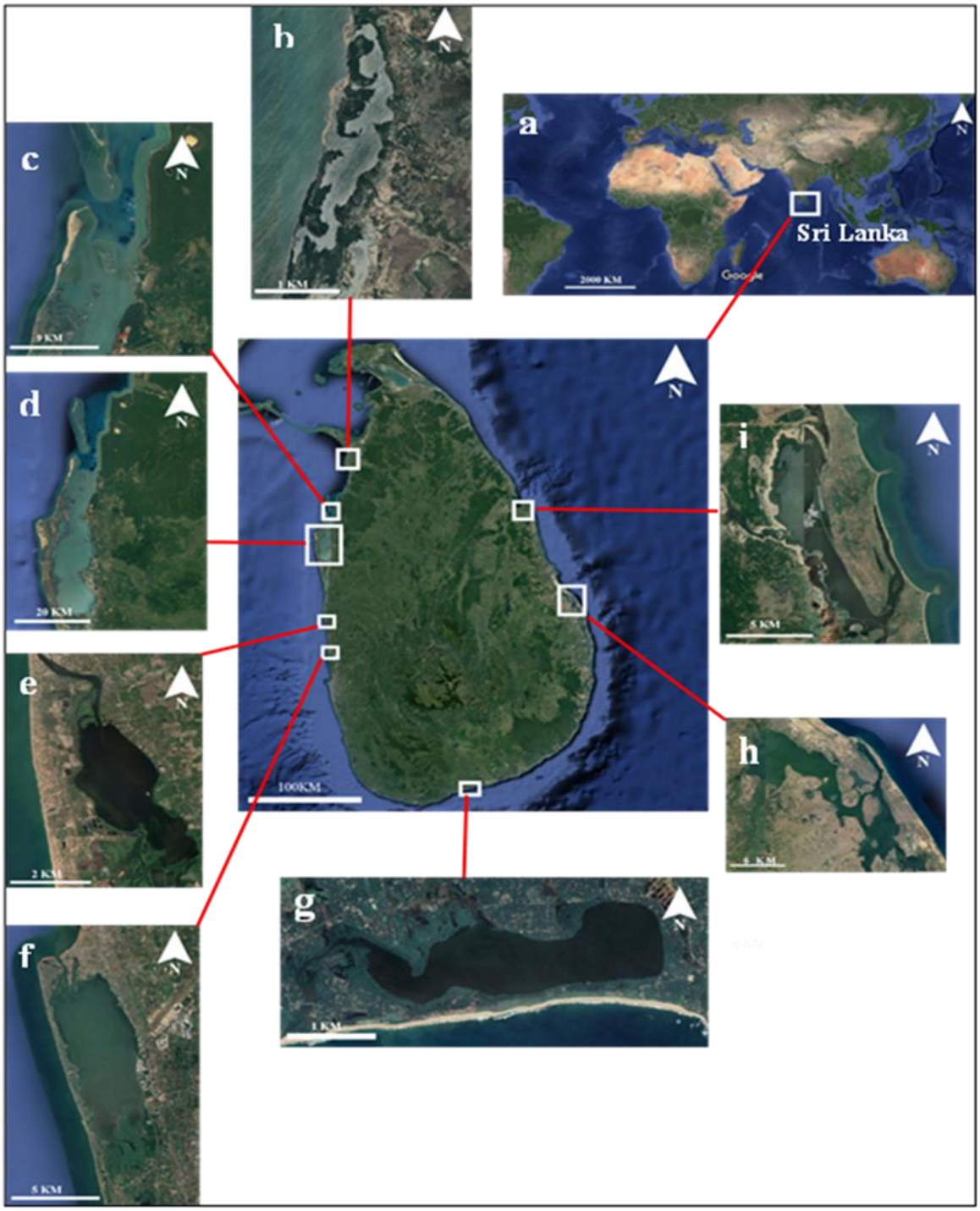


**Figure 2: Locations where the mangrove carbon assessment studies have been conducted in Sri Lanka a) Location of Sri Lanka b) Malwathu Oya estuary c) Kala Oya estuary d) Puttalam – Kalpitiya lagoon e) Pambala – Chilaw lagoon f) Negombo Lagoon g) Rekawa lagoon h) Batticaloa lagoon i) Uppar lagoon (Source: Perera & Amarasinghe, 2018, Perera et al., 2018, Jonsson & Hedman, 2019, Perera & Amarasinghe, 2019, Cooray et al., 2021)**

Soil samples were taken from three different depths; 0-15 cm, 15-30 cm and 30-45 cm of mangrove sites. Total soil organic carbon content was measured by chromic-acid wet oxidation method followed by colourimetry. According to Perera & Amarasinghe (2019), 0-15 cm layer has obtained a higher amount of carbon in mangrove soils of wet and intermediate climatic zones [51]. The largest carbon sink (580.84 ± 32.91 Mg $ha^{-1}$) was reported in the Rekawa lagoon (intermediate zone) and the lowest carbon sink (316.29 ± 33.8 Mg $ha^{-1}$) was reported in Batticaloa lagoon (dry zone) in Sri Lanka (Figure 3).

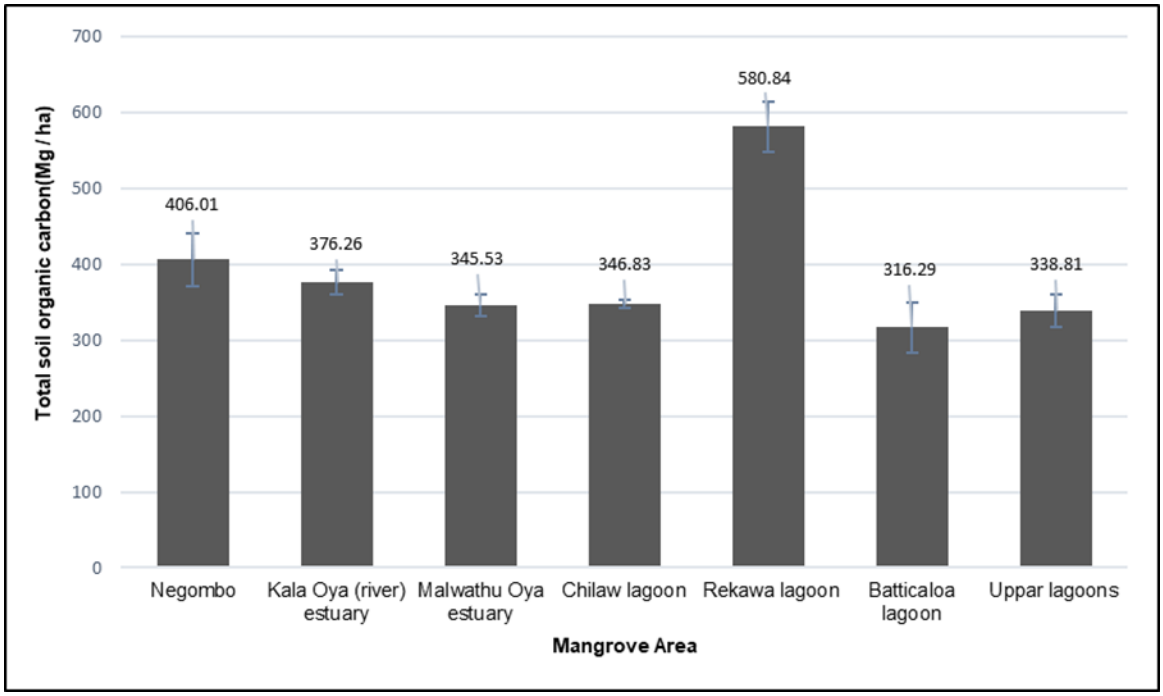


**Figure 3: Total soil organic carbon in selected mangrove areas in Sri Lanka (Source; Perera & Amarasinghe, 2019)**

One of the key results describes that there is a significant correlation ($p < 0.05$) between total soil organic carbon stocks in mangroves with annual rainfall. This study revealed that the total organic carbon content of Sri Lankan mangrove soils are two times higher than the total organic soil carbon content of tropical savanna forest in Yap and Palan island in the Pacific Ocean (146–198 Mg $ha^{-1}$) [14] and mangrove soils at Hooker Bay, San Andres Island (90–160 Mg $ha^{-1}$) [17]. Interestingly, according to the results of Perera & Amarasinghe (2019), the total organic carbon content of Sri Lankan mangrove soils (118–424 Mg $ha^{-1}$) is in a higher range among the other global mangrove soil carbon pools [5, 51].

A study has been conducted by Cooray et al, (2021) to assess the above ground and below ground carbon stocks, selecting five mangrove sites; Rekawa lagoon, Pambala-Chilaw lagoon, Puttalam-Kalpitiya lagoon, Batticaloa lagoon, Negombo lagoon, situated in three climatic zones (dry, intermediate and wet zone) in Sri Lanka [10]. The important fact in that study was, soil samples were taken from up to the maximum depth that soil corer penetrated. Soil samples were taken from eight different depths; 0-15cm, 15-30 cm, 30-45 cm, 45-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150 cm < (to the maximum depth or bedrock). Root samples were taken from four different depths; 0-15 cm, 15-30 cm and 30-45 cm, 45-60 cm. Total soil organic carbon content was measured by the loss on ignition (LOI) method using a muffle furnace and the total root carbon content was measured by multiplying the oven dried weight of roots with the conversion factor of 0.39 given by [26]. Whereas above ground biomass was measured by common allometric equation (a) given by [30] and above ground, carbon was measured using equation (b).

$$\text{Above ground biomass (AGB)} = 0.251.d.D^{2.46} \quad \text{(a)}$$

$$\text{Above ground carbon} = AGB \times 0.48 \quad \text{(b)}$$

Where, AGB = Above ground biomass (kg), d = wood density (g $cm^{-3}$), D = diameter at breast height (cm). According to the results of Cooray et al, (2021), the highest total organic carbon stock was reported in the Rekawa lagoon (1455.39 ± 45.16 Mg C $ha^{-1}$) and the lowest total organic carbon stock was reported in the Batticaloa lagoon (734.75 ± 57.68 Mg C $ha^{-1}$) (Figure 4) [10]. Above ground carbon and below ground root carbon were ranging from 75.5 to 189.1 Mg C $ha^{-1}$, 7.9 to 14.3 Mg C $ha^{-1}$ respectively. This study has revealed that soil carbon contributes 83% - 90% of

 

the total organic carbon stock in selected sites in Sri Lanka.

Soil sampling depth is one of the most important factors that should be considered when assessing the carbon stocks in blue carbon ecosystems. Previous studies have shown [13, 51] that the higher amount of soil carbon contained in the upper 0-30 cm of the soil and it is the common and standard method of taking samples from the upper 100 cm. According to Cooray et al. (2021), the sample depth influenced the precise estimation of the carbon stock of a particular mangrove ecosystem [10]. If the samples have not been taken from up to the maximum depth, it will have a high tendency to give underestimation values for the carbon stock of a particular mangrove ecosystem [6, 10]. Therefore, Cooray et al. (2021) suggested that soil sampling depth should be taken into account when estimating total soil organic carbon content in a particular mangrove ecosystem [10].

Jonsson & Hedman (2019) have conducted research to investigate the total organic carbon stocks in three sites; Kokkaddicholai, Manmunai bridge island and Kannankudah in Batticaloa lagoon (obtaining 14.2 $km^2$ mangrove area), in Sri Lanka [22]. Samples were taken from three different depths; 0-30 cm, 30-60 cm and 60-80 cm of mangrove soil. The Walkley-Black procedure [63] was used to measure the soil organic carbon content and general allometric equations were used to measure the above ground carbon stock in mangroves [8, 19, 26].

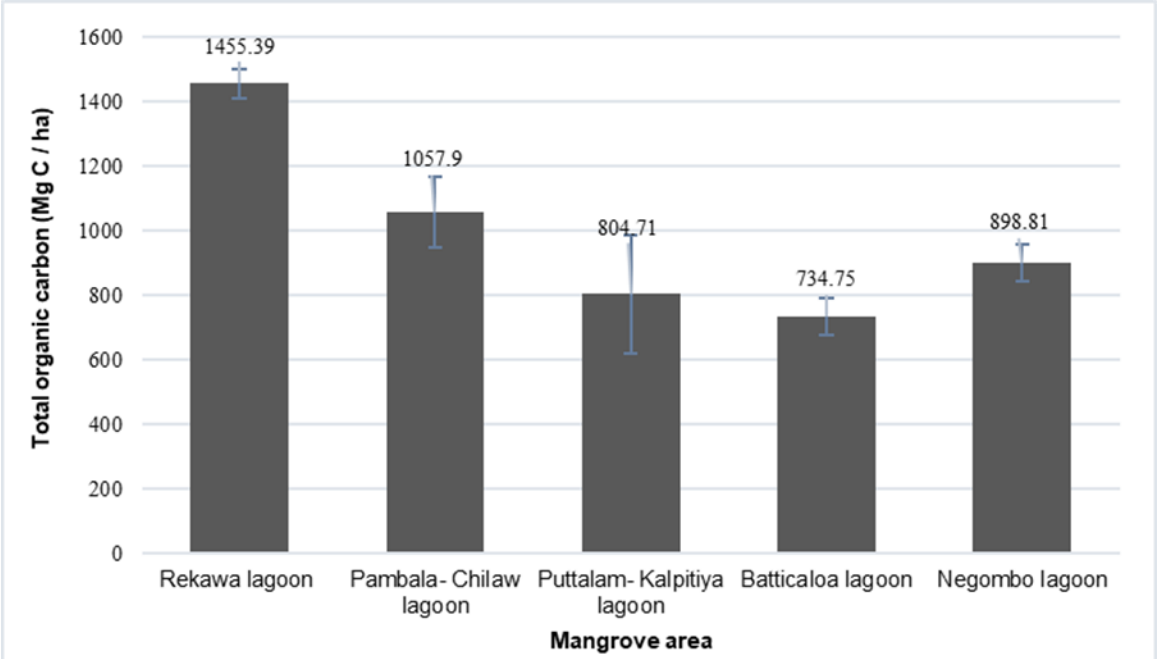


**Figure 4: Total organic carbon in selected mangrove areas in Sri Lanka (Source; Cooray et al., 2021)**

The total organic carbon stocks have resulted in Kokkaddicholai, Manmunaibridge island and Kannankudah sites: 100.9 kg C $m^{-2}$, 786.4 kg C $m^{-2}$, 593.1 kg C $m^{-2}$ respectively. The study which was conducted by Jonsson & Hedman (2019), has provided a basic estimation of carbon stocks in the Batticaloa lagoon [22].

Another study was carried out by Perera & Amarasinghe (2018) to investigate the total organic carbon content in the Batticaloa lagoon in Sri Lanka [50]. Samples were taken from three different depths; 0-15 cm, 15-30 cm and 30-45 cm of mangrove soil. Chromic-acid wet oxidation method was used to measure the soil organic carbon content and species specific allometric equations and common allometric equations were used to measure the above ground and below ground biomass. The above study revealed that the obtained total organic carbon was 506.40 ±36.04 Mg C $ha^{-1}$ while the total soil organic carbon, total aboveground carbon and total root carbon amounts were 347.83 ±33.80 Mg C $ha^{-1}$, 131.60 ±1.62 Mg C $ha^{-1}$, 26.96 ±0.26 Mg C $ha^{-1}$ respectively. According to Perera & Amarasinghe (2018), mangrove soil is responsible for sequestrating a comparatively large fraction (68%) of organic carbon [50].

Perera et al. (2018) have conducted research to quantify the carbon stocks in the Negombo lagoon area in Sri Lanka [52]. Samples were taken from three different depths; 0-15 cm, 15-30 cm and 30-45 cm of mangrove soil. Total soil organic carbon content was measured by the rapid-dichromate oxidation method and species specific allometric equations as well as common allometric equations were used to measure the above ground and below ground biomass. According to the results, the total organic carbon, soil organic carbon, above ground carbon and below ground root carbon amounts were 499.54 ± 6.35 Mg

 

C $ha^{-1}$, 418.98 ± 5.19 Mg C $ha^{-1}$, 65.31 ± 0.97 Mg C $ha^{-1}$, 15.25 ± 0.19 Mg C $ha^{-1}$ respectively. Further, this study suggested that factors such as hydrological and oceanographic alterations and anthropogenic processes affect the carbon sequestration of the above site.

A high carbon amount is stored in the upper 30 cm of the soil and could be easily disturbed due to anthropogenic activities. As a result, the oxidation process of soil organic matter will occur with rapid carbon dioxide emission [3, 36, 60]. The average soil organic carbon amount of the upper layer (100 cm) of mangrove soil is 404.37 Mg C $ha^{-1}$. Therefore, 1484.04 Mg $CO_2e$ ($CO_2e$ = soil carbon dioxide equivalent) could be emitted from the deforestation of each hectare of the mangrove ecosystem, which is higher than the value; 1060 Mg $CO_2e$ $ha^{-1}$ reported for the estuarine mangrove sediments globally (McKinley et al., 2011). According to Giri et al. (2015), 242 ha of mangroves area have lost between 2000 to 2012 [15]. It resulted in a 29,933.09 Mg $CO_2e$ emission per year and interestingly, Cooray et al. (2021) have estimated that if all mangrove areas located in Sri Lanka (approximately 8000 ha) are disturbed, ~ 12.72 × 106 Mg $CO_2e$ will be emitted to the atmosphere [10]. Therefore, the conservation of mangroves and the other blue carbon ecosystem should have taken much attention.

## 4. Threats and challenges for effective conservation of blue carbon ecosystems

As we discussed earlier, blue carbon ecosystems have been threatened mainly due to the various anthropogenic activities [35]. In Sri Lanka, 20.17 ha of mangrove area has been degrading per year [15] caused by development programmes, converting mangrove ecosystems into agricultural lands, building artificial infrastructures (e.g., house constructions, hotels, industrial buildings) and especially shrimp farming [12, 16, 25, 29].In addition to that, the lack of a proper monitoring system to detect the mangrove forest degradation, limited knowledge of people about the ecosystem services and values of mangroves, have driven to the degradation of mangrove forests in Sri Lanka [12, 16]. However, the present Sri Lankan government is in the process of taking necessary action to conserve all remaining mangrove forests and planned to restore 10,000 ha of coastal wetlands under the United Nations Decade of Ecosystem Restoration programme in Sri Lanka [10].

Seagrass meadows are one of the highly threatened ecosystems in Sri Lanka [62] due to unsustainable and destructive fishing activities, eutrophication (Negombo lagoon has lost 20% of seagrass meadows caused by microalgal proliferation on seagrass meadows) and digging of polychaetes causing siltation [24, 49, 62]. According to Ranahewa et al. (2018), anthropogenic activities such as nutrient and sediment loading, expansion area extension of salt pans, shrimp farming, the extension of buildup areas and expansion of man-made infrastructure have increased the rate of the sea bed degradation [53]. The conservation of seagrass meadows in Sri Lanka has not yet been recognized as an important matter [44]. However, there are research studies that have been conducted to investigate the diversity, abundance and distribution of seagrass species in Sri Lanka [20, 33]. Moreover, Udagedara & Dahanayaka, (2020) have prepared a checklist, focusing on diversity, distribution and conservation of seagrass species in Sri Lanka [62]. In addition, national seagrass meadows monitoring system and conservation policy plan should be established towards sustainable coastal zone management through conserving seagrass meadows as a valuable blue carbon ecosystem in Sri Lanka.

Less attention has also been given to the tidal marshes in Sri Lanka, though they are called tidal marshes in the temperate areas which are macro-tidal, Sri Lankan vegetation classification named them as salt marshes and they are markedly different to tidal marshes with respect to species composition, structure and functioning, compared to the mangroves and seagrass meadows. The coastal communities have not identified the importance of salt marshes since their importance is not as direct as mangroves [45]. Salt marshes are the nursery grounds for many culturable fish species, especially due to the presence of algal species (green algae and cyanobacteria). Shrimp farming is the major threat to salt marshes, especially in the Puttalam lagoon area in Sri Lanka. In addition, people use salt marsh areas to build houses that reduce the extent of salt marshes in Sri Lanka [45]. Therefore, policy enforcement to conserve salt marsh areas is critical in Sri Lanka. Moreover, research should be carried out to assess the carbon stocks and their distribution as well as to evaluate the socio-economic importance of salt marshes.

## 5. Policies and legislations to conserve blue carbon ecosystems in Sri Lanka

Sri Lankan government has endorsed policies and legislations in the country's constitution for the

 

protection of coastal wetlands including mangroves as a blue carbon ecosystem [10, 23]. Sri Lanka is in the vanguard of mangrove conservation along with the other countries in the world [10, 28]. In 2020, "The National Policy on Conservation and Sustainable Utilization of Mangrove Ecosystem in Sri Lanka" has been established. However, we believe that implementation and monitoring of appropriate action plans (realistic) is the key to conserve mangrove ecosystems and their blue carbon stocks and Sri Lanka still has to materialize it. In addition, The Fauna and Flora Protection Ordinance furnishes the protection of animals (both invertebrates and vertebrates) and plants (including mangroves). Furthermore, the Fisheries and Aquatic Resources Act provides legal protection for the aquatic resources to avoid the extinction of some aquatic species that reside in lagoons and estuaries and intern it will also protect the mangrove forests located in those ecosystems.

Sri Lanka has signed several international conventions to protect the blue carbon ecosystems and is obliged to follow and obey their statutes i.e., Convention of Biological Diversity (CBD) and United Nations Framework Convention of Climate Change (UNFCCC). Sri Lanka is also a signatory to the Paris Agreement (21st session of UNFCCC Conference, 2015 in France) and submitted Nationally Determined Contributions (NDC) in 2016 (Ministry of Mahaweli Development and Environment, 2016) emphasizing the protection, conservation and restoration of mangroves and seagrass meadows as well as the other ecosystems towards climate change mitigation. Interestingly, Sri Lanka has prepared a National Biodiversity Strategic Action Plan (NBSAP) for the period 2016 – 2022 following the Convention of Biodiversity (Article 6 of CBD) which highlights the importance of mangrove restoration and the capacity improvement of ecosystem services.

## 6. Knowledge gaps in blue carbon dynamics in Sri Lanka

Scientists have been continuously studying strategies to reduce the increment of atmospheric $CO_2$ levels as it gives rise to critical global environmental problems such as global warming, glaciers melting and sea level rising [32]. Therefore, blue carbon ecosystems have been identified as the best natural systems that are capable of capturing and storing $CO_2$ within their biomass and soil environment [26]. For that, the total blue carbon content of a particular country should be quantified to get a clear understanding of the current carbon pool [10]. Therefore, blue carbon stocks in mangroves, tidal marshes and seagrass meadows in Sri Lanka should be quantified precisely. According to the best of our knowledge, blue carbon stock assessment studies of tidal salt marshes and seagrass meadows are scanty in Sri Lanka. It would be hard to estimate the total blue carbon content, without assessing the carbon stocks in tidal marshes and seagrass meadows extensively in Sri Lanka. Few research studies have been conducted to estimate carbon stocks in mangrove sites, covering the largest existing mangrove areas in the major climatic zones in Sri Lanka, to provide an understanding sufficient to have an insight into the overall potential of Sri Lankan mangrove ecosystems in sequestering atmospheric carbon and the magnitude of mangrove blue carbon pool [10, 22, 50, 51, 52]. Most of the studies have been conducted by taking soil samples 0 - 80 cm depth range of a carbon stock at a particular mangrove site since mangrove areas in Sri Lanka, which are micro-tidal, often have very shallow anaerobic soil layers and the many studies reveal that the soil organic carbon content that had fixed by the mangrove vegetation currently occupying the site, decreases with depth. Organic carbon in deep soils may indicate geological changes that have occurred in locations and changed the vegetation types and processes that assist the burial of organic carbon produced by the plants. Therefore, the deep soil carbon content may not necessarily represent the carbon sequestration capacity of the current vegetation [22, 50, 51, 52]. If the facilities are available, it is also recommended to take soil samples from the maximum depth that soil corer penetrates in a mangrove ecosystem as possible [10]. One study has focused on assessing soil organic carbon in seven mangrove sites in Sri Lanka [51]. Carbon emission data are an important factor to study the blue carbon dynamics in any country. Blue carbon sequestration processes (mangrove primary productivity) are even more important in having an insight into the potential of these blue carbon ecosystems in capturing and storing atmospheric carbon. Amarasinghe and Balasubramaniam (1992) have investigated the NPP (Net Primary Productivity) of above ground mangrove forest stands on the northwestern coast of Sri Lanka, using the litterfall data and above ground biomass increment. Interestingly, the NPP of fringing mangrove stands is lower than the estuarine mangrove stands [66]. The Gross primary productivity of mangrove stands at

 

Kadolkele in Meegamuwa (Negombo) estuary, Sri Lanka has been affected by the key factors such as; stem density, plant height, species richness, and leaf area index [67]. In addition to that, a significant relationship ($p < 0.05$) has been shown between the structure of vegetation which is represented by complexity index, NPP, and organic carbon accumulation rate in mangroves [68].

The factors that affect the carbon sequestration and storage of blue carbon ecosystems should be investigated to get an understanding of the capability of sequestrating and storing carbon in high capacity within their ecosystem pools. Perera & Amarasinghe (2019) have described that there is a significant correlation ($p < 0.05$) between total soil organic carbon stocks in mangroves with annual rainfall and Cooray et al. (2021) revealed that the mangrove soil carbon stock was higher where the vegetation biomass and stand densities are high [10, 51]. According to the Wijerathna et al., (2021), Soil porosity, soil moisture content, conductivity and salinity positively correlated with the soil organic carbon content while soil bulk density and nitrate content negatively correlated with soil organic carbon content (Spearman rank correlations; $P<0.001$) [69]. Besides, not all the factors will affect the mangroves, salt marshes and seagrass meadows similarly and that knowledge is essential for sustainable coastal zone management. In addition, evaluation of direct and indirect values of blue carbon ecosystems in Sri Lanka is critical and it would be supported by policy enforcement, conservation of coastal zone and proper soil carbon management. Except for a few studies based on mangroves of Batticaloa lagoon and Mannar area, salt marshes and seagrass meadows have not yet been characterized for their primary productivity and their potential for sequestering atmospheric carbon. With the current thrust on aquaculture development in the coastal areas, these blue carbon ecosystems become most vulnerable.

## 7. Limitations

Sri Lankan blue carbon research lack data on the carbon sequestration capacity of salt marshes and seagrass meadows, both in plant biomass (above and below ground) and in soil. Research is needed to fill this gap along with generating data on their current extents and distribution. This domain is not a priority of national research and therefore the state sponsorship is marginal.

## 8. Conclusion

Blue carbon ecosystems are recognized for their important role in climate change mitigation always combating the global climate crisis sequestering and storing significant amounts of atmospheric carbon dioxide in their biomass and soil despite their limited area coverage relative to other ecosystems. Few studies have been focused on quantifying carbon stocks in mangroves and the data of carbon stock assessments in tidal salt marshes and seagrass meadows are scanty in Sri Lanka. Quantifying carbon stocks in the remaining blue carbon ecosystems in Sri Lanka is critical. Similar to the mangrove ecosystems, it is highly recommended to impose policy enforcement to conserve remaining tidal salt marshes and seagrass meadows for climate change mitigation through proper coastal zone management in Sri Lanka.

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