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# Journal of Tropical Environment

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

**Volume 2, Issue I, June 2022**

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# Editorial Note - Journal of Tropical Environment

On behalf of the Journal of Tropical Environment, we are pleased to write the editorial note for Volume 2 Issue I of the journal. The Journal of Tropical Environment was published with two issues per year.

Environmental Management discipline covers contemporary environmental issues and problems and their management strategies. In view of that, the discipline encompasses natural sciences, social sciences, management and philosophy when these disciplines addresses issues related to environmental management in addition to articles addressing directly environmental management issues. Accordingly, the Journal of Tropical Environment consider research articles comes under above scope with a focus on tropical environment.

This issues of the journal presents articles after rigorous double blind review process. Broad range of research papers presented here covers urban heat island phenomena in a small-scale city, phytoremediation potential of different wetland plants suitable for 'mini wetlands', local community perception of agro-tourism, cost of household air pollution, adapting sustainable development goals in sustainability reporting by listed firms, organic liquid fertilizers and their potential impacts on the growth and yield of agricultural crops, performance of biofilm enriched rock phosphates, and environmentally sustainable approaches for the utilization of agricultural wastes for ensuring global food security. Selected several articles cover issues related to sustainable agriculture showing the importance of food security in sustainable development. Others are related to tropical ecosystems, environmental problems related with climate change and urbanization, managing air pollution and environmental sustainability addressed by firms. Articles ensemble a group of issues related to the management of tropical environment and it is expected to incooperate the findings to sustainable development efforts of relevant state and private sector development agencies.

We would like to thank all authors for their contribution and patience, editorial board members and expert reviewers. Their direction and support create the "Journal of Tropical Environment" possible, and also we are sincerely obliged for the comments, support, and strength to the success of the journal. As always an ending message, we would like to send our best wishes to all scholars.

Dr. JMSB Jayasundara

Dr. PSK Rajapakshe

Co-Editor in Chief,
Journal of Tropical Environment-
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# ARTICLES

JOURNAL OF TROPICAL ENVIRONMENT
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Department of Environmental Management
Faculty of Social Sciences & Humanities
Rajarata University of
Sri Lanka

# Determination of urban heat island phenomena in a small-scale city, based on Landsat 8 data; a case study of Gampola urban area, Sri Lanka

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**Abstract**

Urban areas generally reflect less and absorb more of the sun's energy due to the surface materials of the urban settings. This absorbed heat increases surface temperatures and contributes to the formation of atmospheric and surface urban heat islands (UHI). Atmospheric UHI can measure, based on air temperature, and surface UHI can calculate based on land surface temperature (LST). High (LST) is normally found within the urban heat islands and therefore, variations of high LST can be used to determine the UHI phenomena of an urban area. Remote sensing (RS) data like Landsat 8 images and geographic information system (GIS) techniques can be used to determine and understand the relationship between LST and urban landscape composition and pattern. The normalized difference vegetation index (NDVI), normalized difference built-up index (NDBI) and urban thermal field variance index (UTFVI) are among the most commonly used landscape indices for examining the spatial and temporal variations of LST. Therefore, in this research, those indicators have been used to determine the LST of the research area. Various studies have been conducted to identify the UHI situation in Sri Lanka. However, most of these studies have focused on either Colombo metro area or Kandy city area. Since small cities are also generating UHI, Gampola has been selected as the research area and this study examines the relationship between LST and some important landscape variables such as NDVI, NDBI and UTFVI and the possibility of occurrence of UHI in Gampola urban area. According to the study, strong evidences have been identified to prove the existence of the UHI within the Gampola city.

**Key words:** *Urban Heat Islands (UHI), Land Surface Temperature (LST), Landsat 8, Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Urban Thermal Field Variance Index (UTFVI)*

## 1. Introduction

Many urban and suburban areas experience elevated temperatures compared to their outlying rural surroundings; this difference in temperature is what constitutes an urban heat island (UHI)(Oke,1997). The UHI, a phenomenon of the higher atmospheric and surface temperature of urban and suburban areas occurring compared to rural surroundings, was first described in 1818**(**Howard,1818).

One major environmental problem caused by a rapid and a not well-planned urbanization is the decrease of vegetation cover in urban regions due to the expansions of impervious surfaces such as building, parking lots, pavements and other constructions. Impervious surfaces consist of artificial structures that are covered by impenetrable materials such as asphalt, concrete, brick, stone, and rooftops (Estoque et al., 2017). These buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist generally become impermeable and dry (USEPA,2008).

Urban areas typically have surface materials, which have a lower albedo than those in rural settings. As a result, built up communities generally reflect less and absorb more of the sun's energy. This absorbed heat increases surface temperatures and contributes to the formation of surface and atmospheric urban heat islands (Estoque et al., 2017). Except these agents, evapotranspiration, and increased anthropogenic heat production also caused to generate the urban heat island (UHI) (Stone et al., 2010).

With this process and reradiating the trapped heat in the night time (Arsiso et al., 2018), the mean annual air temperature of a city with one million people or more can be 1–3 ºC warmer than its surroundings in the daytime, and, on a clear, calm night, the temperature difference can be as much 12 ºC (Oke,1973). Even smaller cities and towns will produce heat islands, though the effect often decreases as city size decreases (Oke,1982).

The heat island effect arises due to the changing nature of our cities, and is the result of a reduction in vegetation and evapotranspiration, a higher prevalence of dark surfaces with low albedo, and increased anthropogenic heat production (Stone, Hess and Frumkin2010).

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The UHI can be classified into two categories: (i) atmospheric UHI, which is measured based on air temperature, and (ii) surface UHI (SUHI), which is calculated based on land-surface temperature (LST) **(**Estoque et al., 2017). Land surface temperature (LST) is a fundamental variable controlling the surface energy balance, and it is involved in physical, chemical, and biological processes of the Earth surface (Oke,1982).

Surface urban heat islands are typically present day and night, but tend to be strongest during the day when the sun is shining (Estoque et al., 2017). High LST is normally found within the urban heat islands and specifically, within the urban hot spots (UHS) **(**Subhanilet al., 2018).

Studying the UHI based on air temperature is a challenging task due to the lack of ground-level data, especially in developing countries (Oba,2017). Many studies have estimated the relative warmth of cities by measuring the air temperature, using land-based observation stations. This method can be both expensive and time consuming and lead to problems in spatial interpolation (Mallick et al., 2008).

Many of the previous studies have also shown the usefulness of using remote sensing and geographic information systems (GIS) techniques to understand the relationship between LST and urban landscape composition and pattern (Ranagalage et al., 2017).

Remote sensing might be a better alternative to the aforesaid methods. The advantages of using remotely sensed data are the availability of high resolution, consistent and repetitive coverage and capability of measurements of earth surface conditions (Owen et al., 1998).

When comes to remote sensing data, Landsat data has free access and it has various bands for different applications. Landsat 8 (formerly the Landsat Data Continuity Mission - LDCM) was launched in 2013. Combined with other Landsat series, it provides continuity with the more than 40-year-long Landsat land imaging data set (Wulderet al., 2016). The thermal infrared sensor (TIRS) with two thermal infrared channels was added to the Landsat 8 payload to support the detection of the urban heat island and there are many algorithms to retrieve the LST from Landsat 8 data (Meng et al., 2019).

The normalized difference vegetation index (NDVI) and the normalized difference built-up index (NDBI) are among the most commonly used landscape indices for examining the spatial and temporal variations of LST. (Kumar & Shekhar,2015)**.** Except those indexes, some researchers have used urban thermal field variance index (UTFVI), since it is important to determining the ecological comfort level of a city is a very important task (Subhanilet al., 2018).

Various studies have been conducted to identify the UHI situation in Sri Lanka. However, most of these studies have focused on either Colombo metro area (Manawadu&Liyanage,2008) (Ranagalage et al., 2017) (Samanmali & Siriwardane,2015) (Senanayake et al., 2013) or Kandy city area (Dissanayake et al., 2019).

Sri Lanka is an Island nation with limited land resources. Even though, Sri Lanka ranks as the fifth least urbanized during the period 1995-2017, urban area grew by 6.42 % year, which is a remarkably high figure even by global standards**(**http://unhabitat.lk/news**).** Since small cities are also generating UHI, (Oke,1982) as a developing country with limited land resources, it is very important to study the UHI situation in other urban areas in Sri Lanka also.

In this research, it is expected to find any evidence of UHI phenomenon in small scale urban area. Gampola has been selected as the research area and moreover, this study examines the relationship between LST and some important landscape variables such as NDVI, NDBI and UTFVI.

## 2. Materials and Methods

### 2.1 Study area

Gampola city, which is located within the Kandy district, central province of Sri Lanka and stands 300 – 500 m in altitude, has been selected as the study area. It is one of Municipal and urban area in Kandy district and according to the population and housing census, 2012. population of the Gampola urban area was 37871 (DCS,2012).

Geographically, this region belongs to the highland complex of Sri Lanka. Mean annual rainfall is in between 3000 – 3500 mm and mean annual temperature is in between 20-25°C (SDSL,2007).

Historically, Gampola was an important city since it was a capital city of the Sri Lanka, in between 1314-1415 AD.

This particular topography features led to the selection of the Gampola urban area as the study area of this study.

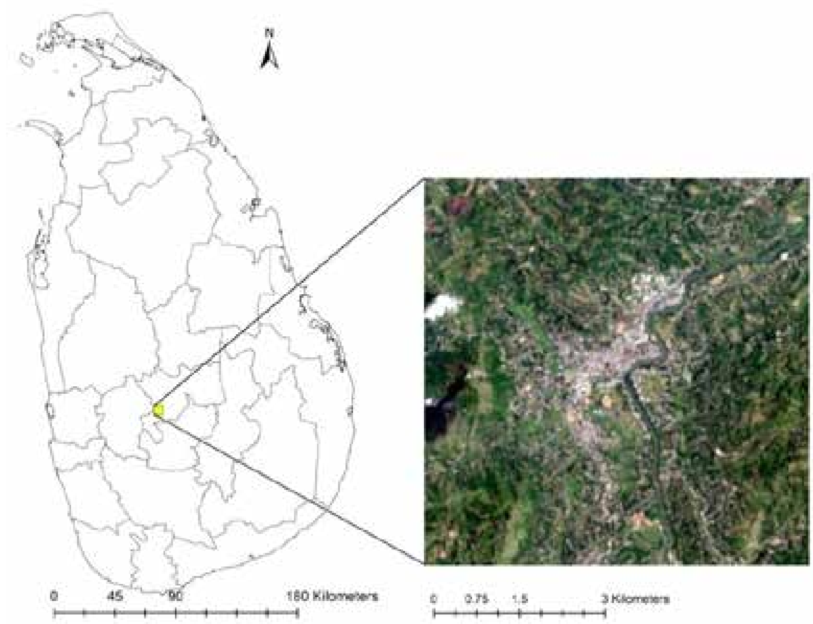


**Figure 1. Location of the study area study area**

In the study, a geographical grid was selected as a study area which bounded by 7°7’52.32” N to 7°11’34.15” N latitude and 80°36’4.68” E and 80°36’4.50” E longitude from the eastern side while 7°7’51.97” N to 7°11’33.96” N latitude and 80°32’25.30” E and 80°32’25.03” E longitude from the western side, while extend of the area is 46 $km^2$. Whole Gampola city was comprised into that grid (Figure 1).

## 2.2. Data set and data processing

For this study, Landsat Level 1(Landsat 8 OLI/TIRS C1 level-1) data provided by the United States Geological Survey (USGS) were used. For the Landsat-8 OLI/TIRS data, the multispectral bands (bands 1–7 and 9) also have 30 m spatial resolution. Its panchromatic band (band 8) has 15 m spatial resolution, while its thermal bands (band 10 and 11) have 100 m spatial resolution, which have also been re-sampled to 30 m by the USGS (https://landsat.usgs.gov).

In the data selection stage, daytime dry-season data, cloud-free images (< 10%), and pre-geo referenced by using Universal Transverse Mercator (UTM) zone 44 north projection data have been extracted.

**Table 1. Key metadata of the Landsat image used**

| Sensor | Scene ID | Acquisition date | Time (GMT) | Season | Cloud cover (%) |
|---|---|---|---|---|---|
| **Landsat-8 OLI/TIRS** | LC81410552019083LGN00 | 24-03-2019 | 04:53:29 | Dry | 8.23 |

## 2.3 Retrieving LST from Landsat thermal band

As first step, TOA (Top of atmospheric) spectral radiance was calculated using below equation (1) (Artis & Carnahan,1982).

$$TOA(L) = M_L \times Q_{cal} + A_L \quad (1)$$

Where, $M_L$ is Band specific multiplicative rescaling factor from the metadata and $Q_{cal}$ Corresponds to band 10. In addition, $A_L$ is band specific rescaling factor from the metadata.

Then TOA to brightness temperature conversation has been calculated using the following equation. (2) In the same step, to obtain results in Celsius (°C), the radiant temperature was adjusted by adding the absolute zero temperature which is -273.15°C.

$$BT = \left(\frac{K_2}{\ln\left(\frac{K_1}{L}\right)+1}\right) - 273.15 \quad (2)$$

Where, $K_1$ and $K_2$ are calibration constants. For Landsat 8 $K_1$ value is 774.8853 and $K_2$ value is 1321.0789.

Once the brightness temperature conversation calculated, to retrieve the LST values, the land surface emissivity (ε) values Equation (3) (Sobrinoet al., 2004) has been derived.

$$\varepsilon = m\,PV + n \quad (3)$$

Where m = (ε − ε) − (1 − εσ) Fεv and n = εs + (1 − εs) εs and εv are the soil emissivity and vegetation emissivity, respectively. For this study, m and n value has taken 0.004 and 0.986 respectively (Sobrinoet al., 2004). PV is the proportion of vegetation, (4) extracted from the NDVI Equation (6).

$$PV = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \quad (4)$$

Where NDVI is the normalized difference vegetation index derived in Equation (4). The $NDVI_{min}$ and $NDVI_{max}$ are the minimum and maximum values of the NDVI, respectively. The emissivity-corrected LST values were then retrieved using Equation (5) **(**Ranagalage et al., 2017).

$$LST = \frac{TB}{1} + (\lambda \times \frac{TB}{\rho})\ln\varepsilon \quad (5)$$

Where TB = Landsat 8 Band 10 (adjusted by the equation (1) and (2)); λ = wavelength of emitted radiance (λ = 10.8 μm for Landsat TIRS Band 10); ρ = h × c/σ(1.438 × 10 – 2 mK), σ = Boltzmann constant (1.38 × 10 − 23 J/K), h = Planck's constant (6.626 × 10 − 34 Js),c = velocity of light (2.998 × 108 m/s), ε is the land surface emissivity **(**Ranagalage et al., 2017).

## 2.4. Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-Up Index (NDBI)

The NDVI is a major indicator of urban climate and its values range from −1 to 1, with positive values representing vegetated areas and negative values representing non-vegetated areas (Zhang et al.,2009). The NDVI is derived by using the surface reflectance of the red band (band 4 in OLI of Landsat 8) and the surface reflectance of the near-infrared band (band 5 in OLI of Landsat 8) Equation (6) (Estoque et al., 2017).

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (6)$$

Where NIR = band 5 for Landsat 8 OLI; wavelength 0.85–0.88 μm) and RED = band 4 (for Landsat 8 OLI; wavelength 0.64–0.67 μm) (Ranagalage et al., 2017).

The NDBI, is an index for identifying and classifying built-up areas or impervious. The positive values of the NDBI indicate built-up areas and those close to 0 indicate vegetation, while the negative values represent water bodies (Zhang et al.,2003. The NDBI was calculated using below equation (7).

$$NDVI = \frac{MIR-NIR}{MIR+NIR} \quad (7)$$

Where MIR = band 6 for Landsat 8; wavelength 1.57–1.65 μm and NIR = band 5 (for Landsat 8 OLI—wavelength 0.85–0.88 μm) (Ranagalage et al., 2017).

## 2.5 Urban thermal field variance index (UTFVI)

A number of thermal comfort indices are available for evaluating the UHI impacts on the quality of urban life (Subhanilet al., 2018). The UTFVI has been used for the ecological evaluation of UHI zones of Gampola city area with UHI. UTFVI has been estimated using the following equation (8) (Zhang,2003).

$$UTFVI = \frac{T_s - T_{mean}}{T_{mean}} \qquad (8)$$

Where $T_s$ is land surface temperature (°C) Tmean is Mean land surface temperature (°C).

## 2.6 Identification of area with UHI

Areas with UHI phenomena can be determined using the Land surface temperature of the study area and UHI was identified by the range of LST determined by the following equation (9) (Subhanil et al., 2018).

$$LST > \mu + þ\, 0.5 \times \delta \qquad (9)$$

Where μ and δ are the mean and standard deviation of LST in the study area, respectively.

### 2.7. Statistical Analysis

Scatter plots were created and a linear regression analysis was performed to determine the relationship between LST and NDVI, between LST and NDBI and between LST and UTFVI. To do this, 500 random points were created. The parameter values of these points were then extracted from the LST, NDVI, and NDBI images.

In addition to these, a temperature profile of the area has been generated in order to examine the distribution of the UHI.

ArcGIS 10.5 and QGIS 3.4.13 were used to do the analysis and MS Excel was used to perform the linear regression.

## 3. Results

## 3.1 Land surface temperature (LST)

The LST map of Gampola at 2019 is shown in Figure 2 and the descriptive statistics of the retrieved LST values are summarized in Table 2. On 24th March 2019 (04:53:29 GMT), the LST in Gampola area ranged from 21.71–35.26 °C, with a mean of 28.23 °C.

Higher LST values were found mostly the more urbanized part of the Gampola city and high LST were mostly concentrated along with the main road of the city (Figure 2). This situation can be identified north to south of the city (Bothalapitiya to Jayamalapura along the Gampola urban area) where most of commercial activities and dominant infrastructures of the city such as bus stand and railway station are located (Google map).

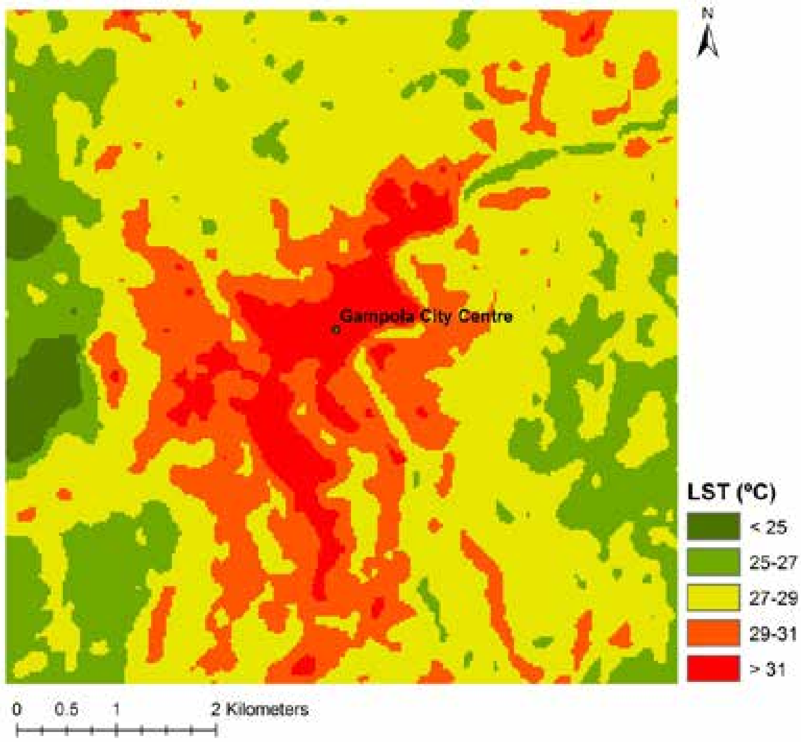


**Figure 2.**
**Land surface temperature (LST) of the study area on 24th March 2019.**

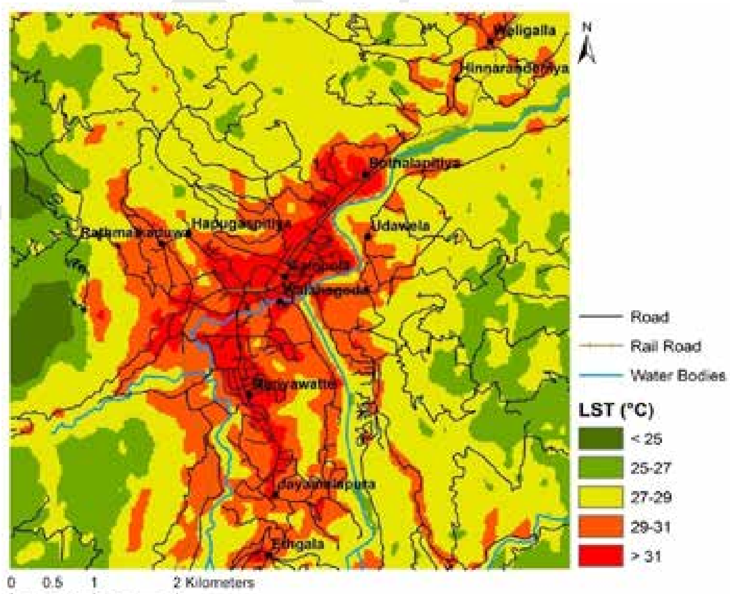


**Figure 3.**
**Land surface temperature (LST) of the study area (with road network and water sources) 24th March 2019**

### 3.2 Normalized Difference Vegetation Index (NDVI)

The NDVI map of Gampola at 2019is shown in Figure 4 and the descriptive statistics of the retrieved NDVI values are summarized in Table 3. On 24th March 2019 (04:53:29 GMT), the NDVI in Gampola area ranged from -0.15 to 0.57, with a mean of 0.39.

Figure 5 shows the scatter plots between NDVI and LST. The regression analysis revealed that LST is negatively correlated with NDVI even though the coefficient of determination ($R^2$) is 0.262.

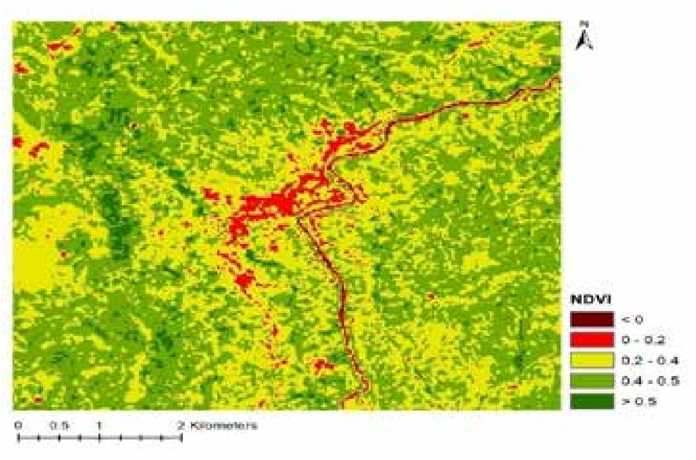


**Figure 4.**
**Normalized Difference Vegetation Index (NDVI) values of study area**

24th March 2019

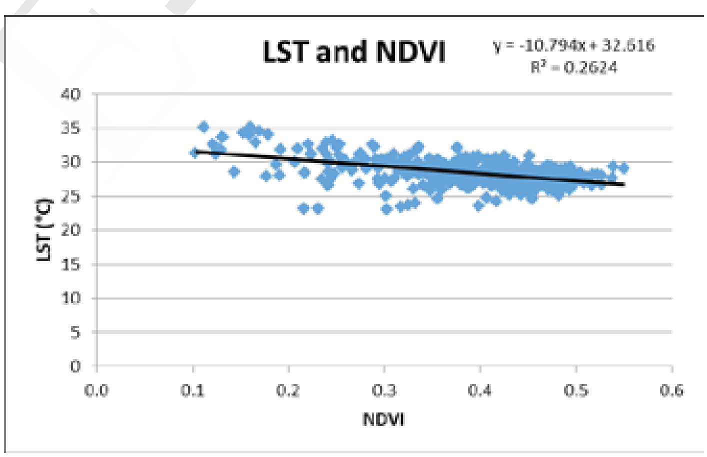


**Figure 5.**
**Relationship between RST and NDVI**

### 3.3 Normalized Difference Built-Up Index (NDBI)

The NDBI map of the Gampola is shown in Figure 6 and their descriptive statistics are summarized in Table 4. The NDBI values ranged from -0.36 to 0.18 in the area. Areas with high NDBI values had greatly distributed from North to South of the city which along with the road network.

The Figure 7 shows the scatter plots between NDBI and LST. When compare with the LST of the area (Figure 2) with the NDBI map, it is clear that those two variables are positively related. Even the scatter plots also indicating a positive linear relationship with $R_2$ value of 0.327. NDBI has more strong relationship with the LST than the NDVI of the area.

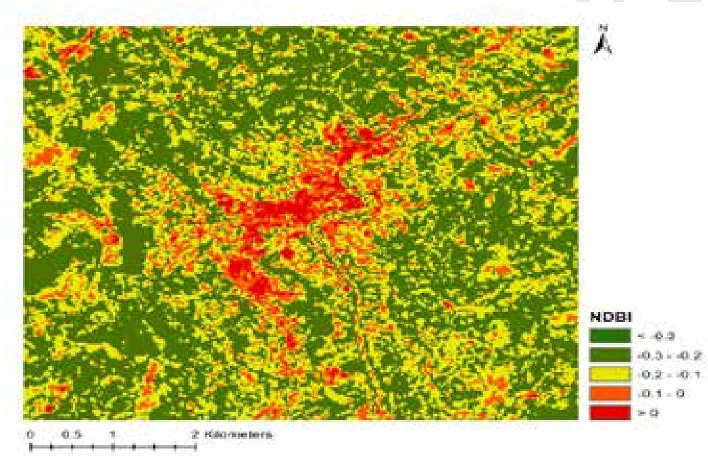


**Figure 6.**
**Normalized Difference Built-Up Index (NDBI) values of study area**

24th March 2019

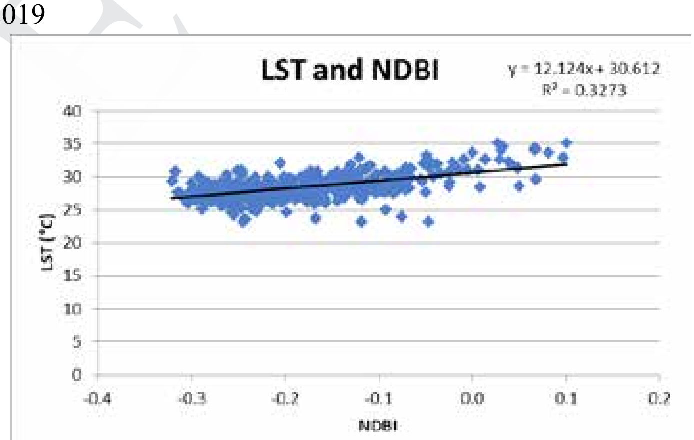


**Figure 7.**
**Relationship between RST and NDBI**

## 3.4 Urban thermal field variance index (UTFVI)

The UTFVI values were divided into six categories according to six different ecological evaluation indices. (Table 5) (Zhang,2003). The UTFVI map of Gampola at 2019 is shown in Figure 8 where areas with high LST has worse ecological evaluation index. There is significant extend of area can be identified in this region, as areas with worst ecological evaluation index.

**Table 5. The thresholds of ecological evaluation index.**

| UTFVI | UHI phenomenon | Ecological evaluation index |
|---|---|---|
| < 0.000 | None | Excellent |
| 0.000-0.005 | Weak | Good |
| 0.005-0.010 | Middle | Normal |
| 0.010-0.015 | Strong | Bad |
| 0.015-0.020 | Stronger | Worse |
| > 0.020 | Strongest | Worst |

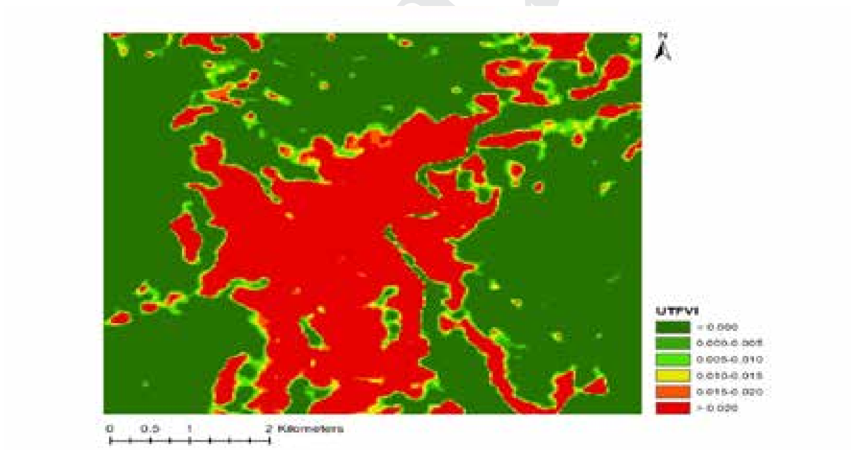


**Figure 8.**
**Urban thermal field variance index (UTFVI) values of study area**

24th March 2019

## 3.5 Urban Heat Island (UHI) situation in the Gampola urban area

Figure 10 shows the distribution of urban heat island phenomena of within the Gampola urban area and figure 11 shows the temperature profile of the study area where can identify the UHI and non UHI areas across the region.

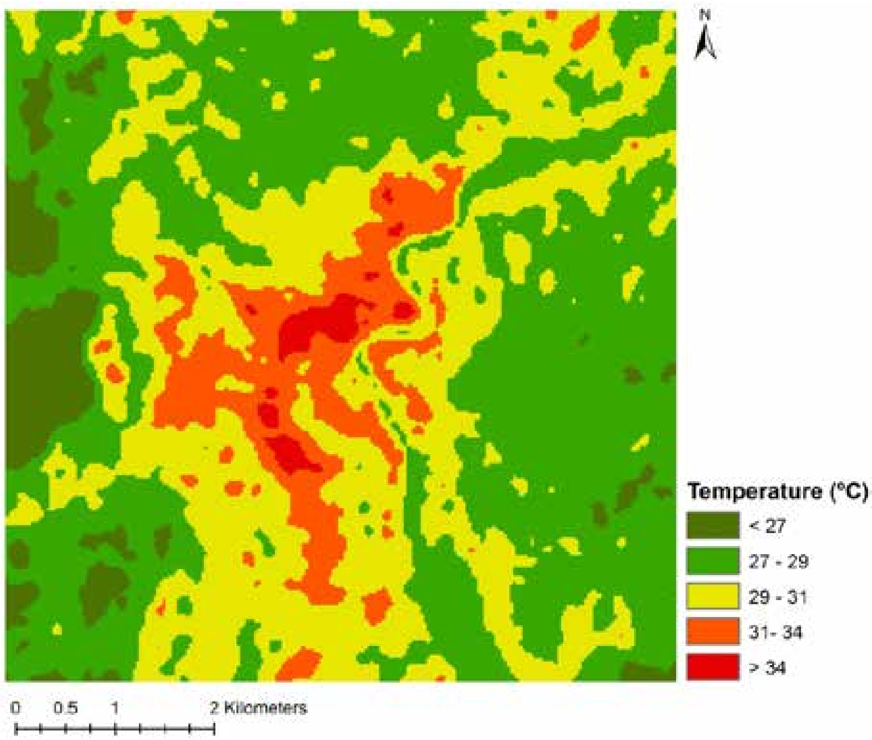


**Figure 09.**
**Distribution of UHI in Gampola urban area**

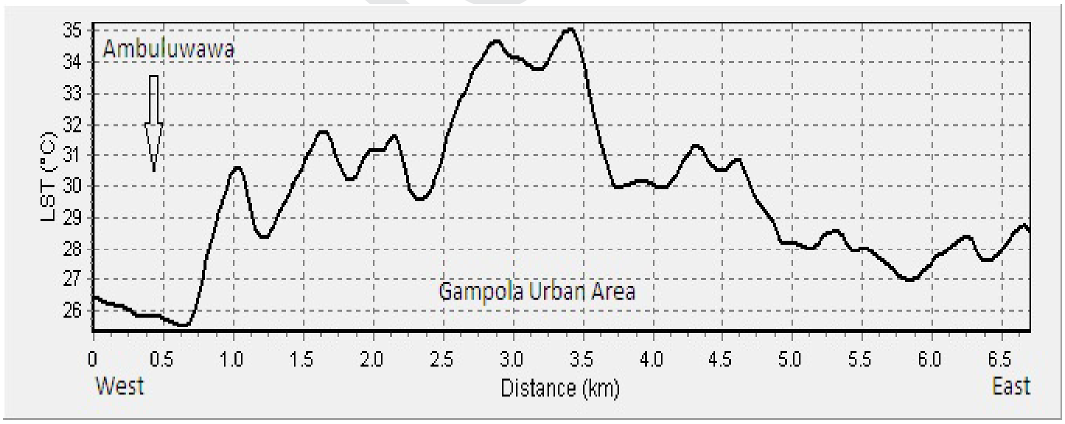


**Figure 10.**
**Temperature profile in Gampola urban area - 24th March2019**

In addition to those, extend of areas with different levels of temperature are shown in the Table 06. According to the table 06, area of around 0.99 $Km^2$ was experiencing temperature which goes more than 34 º C when this image was captured.

**Table 6. Extend of areas (in $Km^2$) with different temperatures - 24th March 2019 (04:53:29 GMT)**

| Value range (ºC) | **< 27** | **27 – 29** | **30 - 31** | **32 - 33** | **34 >** |
|---|---|---|---|---|---|
| Area ($Km^2$) | 1.54 | 29.59 | 11.28 | 2.64 | 0.99 |

## 4. Discussion

In Sri Lanka, Colombo and Kandy urban areas have been examined in terms of the UHI phenomena. Colombo is a coastal city and some studies have indicated that ocean has significant impact on lowering of the LST, which is directly impact with the UHI **(**Senanayake et al., 2013). Being located in the central high lands, Gampola urban area is placed in different topographic setting than the Colombo city.

However, Kandy urban area is more similar to the Gampola urban area in terms of the climatic conditions and the landscape. Studies have shown that the rapid growth of urbanization is the major cause for the increased UHI situation in the Kandy urban area (Dissanayake et al., 2019).

According to the research results, it is clear that not even in wide spread urban areas like Colombo or Kandy, but also small-scale urban areas can be having UHI situation.

The intensity of UHI may be defined as the difference between the average temperature of UHI and non-UHI) (Subhanil et al., 2018). Gampola urban area is an area with high dense of build-up structures according to the NDBI index (Figure 6). City has spread along with the Peradeniya-Hatton road from North to south with a linier pattern. In addition, NDVI values of the urban area is significantly low (Figure 4) and LST of that area is much greater comparing with the surrounding area (Figure 2 and Figure 11). Ecologically also Gampola urban area is in a worst situation according to the UTFVI values and it also indicating that the city is experiencing UHI for some extend (Figure 8).

According to the satellite data, minimum LST of the area was 21.71 ºC and the Maximum was 35.26 ºC when the satellite image was capturing. Extend of the study area was around 46 $Km^2$ and even it is a small area, by that time; temperature difference is much greater between the urban center and other suburbs. Around 61.4% from the total land area was experiencing more temperature than the mean temperature (28.23ºC) of the area (Table 6). In addition, when consider about the temperature profile of the area, it is possible to identify considerable temperature incensement within the heart of the city compare with the surrounding area which can be defined as a UHI situation (Figure 11).

Various studies have suggested different mitigation strategies including Enhancing vegetated spaces in urban areas or the concept of the land-use mixture (a mixture of impervious surfaces and green spaces) (Galagoda et al.,2018). Gampola urban area is surrounded by some natural protected areas such as Ambuluwawa. If it is possible to increase the area of dense vegetation within these protected lands, that will be highly effective on reducing the LST within the Gampola urban limits. In addition to that, strategies such as land-use mixture and urban agriculture can be used to reduce the LST in the area and that will be causing to prevent the UHI phenomena in the Gampola urban context.

## 5. Conclusion

In this study, objective was identifying the UHI phenomena within a small urban area in Sri Lanka with the spatial distribution and the pattern of the LST and Gampola urban area and suburb was selected as the study area.

According to the study, strong evidences have been identified to prove the existence of the UHI even within small-scale urban areas also.

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# Phytoremediation potential of different wetland plants suitable for mini- wetland units

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## Abstract

Phytoremediation by plants has been a significant technology to remediate wastewater in constructed wetlands (CWs). However, the requirement of a larger land area is a major limitation for its use. Small scale CW units can be the best option for domestic greywater treatment since it reserves limited land area. This study aimed to identify the most effective plant combinations for phytoremediation using mini- wetland units. The CW units were constructed using plastic containers (55*30*30 cm). Eight treatments; in a combination of selected wetland plants Vetiver (Vetiveriazizanioides), Kangkung (Ipomoea aquatic), Kohila (Lasiaspinosa)were tested and soil without amendments were served as a control. Wastewater was synthesized, similar to the domestic greywater, and fed into CW units at the rate of 0.5Lh$^{-1}$. The hydraulic retention time was 63hours. Phosphate Phosphorus ($PO_4^{-3}$-P), Nitrate Nitrogen ($NO_3^-$ - N), Ammonium Nitrogen ($NH_4^+$-N), Total Dissolved Solids (TDS), pH, Electrical Conductivity (EC), and certain trace elements were monitored both in influent and effluent in two-week intervals for two months. The experiment was conducted in a completely randomized design (CRD) with three replicates. Results revealed that each combination of wetland plants recorded an increasing pollutant ($NH_4^+$-N, $NO_3^-$ - N, $PO_4^{-3}$-P, TDS, pH,) removal efficiencies (REs) throughout the monitoring period. Plant combination of Kangkung, Kohila, and Vetiver showed significantly ($p<0.05$) higher performance in removal of $NH_4^+$-N, $NO_3^-$ - N, $PO_4^{-3}$-P with the REs of 62%, 66%, and 65% respectively. After the treatment process; in all treatments, pH and TDS of the effluents were ranged around the permissible level following the general standards for wastewater. The overall results conclude that small-scale CW units are a viable technology for greywater treatment at the domestic level with the combination of Kangkung, Kohila, and Vetiver. Further studies are recommended for a concrete conclusion.

**Keywords:** *Constructed wetlands, Greywater treatment, Removal efficiencies, Wetland plant.*

## 1. Introduction

The use of constructed wetlands for wastewater treatment is becoming widespread throughout the world due to the demand for water-quality improvement and the increasing need for wastewater reclamation and reuse(Jinadasa *et al.*, 2006). Constructed wetlands (CWs) are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewaters(Vymazal, 2005) also have been identified as a sustainable wastewater management option for developing countries(Mejare and Bulow 2001).

In most countries, constructed wetlands have been used for domestic wastewater treatment, and this technology can be useful for application in rural settings and, possibly, urban areas where space is not a constraint. The Constructed wetlands are cost-effective, technically feasible, and less expensive to build than other treatment options, Low operation and maintenance expenses. In this regard, the limited land area is the major constrain with this CW technology in urban cities. Therefore, this study is mainly focused to treat wastewater by using a small container constructed wetland unit with some selected wetland plants and identify the most effective combination of wetland plants for phytoremediation of pollutants in wetlands.

## Methodology

The study was conducted at the Faculty of Agriculture, Rajarata University of Sri Lanka under greenhouse conditions. Small plastic containers (55×30×30 cm) were filled with aggregates from the bottom (5 cm) and then topsoil (15 cm) as filling materials. PVC pipes 125 mm diameter with valves were used to feed the synthesized wastewater. Domestic wastewater was synthesized (Hemanthika, 2016) and applied at the rate of 1.25 ml/ s using perorated PVC pipes.

Different combination of selected wetland plants; Vetiver grass (*Vetiveria zizanioides*), Lasia/ Kohila (*Lasia spinosa*), Water spinach/ Kangkung (*Ipomoea aquatica*) were used as treatments (Table:1). Clean water was fed to wetland units for up to two weeks to initiate the wetland plant growth. Eight treatments (Table 1) were tested in Completely Randomized Design (CRD) with three replicates. The experiment was continued for up to two months.

**Table 1: Treatments used for the experiment**

| | Treatment |
|---|---|
| T1 | Vetiver plant only |
| T2 | Kohila plant only |
| T3 | Kangkung plant only |
| T4 | Vetiver + Kohila |
| T5 | Vetiver + Kangkung |
| T6 | Kohila+ Kangkung |
| T7 | Vetiver + Kohila + Kangkung |
| T8 | Control |

Water samples were taken at two weeks interval for two months both from inlet and outlet and analyzed for pH, Electrical conductivity (EC), Total Dissolved Solids (TDS) using a multi-parameter. Dissolved Oxygen (DO) concentration was measured using a DO meter. Phosphate-phosphorous ($PO_4^{3-}$-P) (Olsen *et al.,* 1954)and Nitrate-nitrogen ($NO_3^-$-N) (Yang *et al.,* 1998) were also determined using standard analytical procedures. Total N (Bremmer, 1982) and P (Olsen *et al.,* 1954) contents of wetland plants were determined initially and at the end of the two months as pant analyses.

Removal efficiencies for each pollutant were calculated using the equation 01 and expressed using Microsoft Excel. SAS software was used for data analysis.

$$\text{Pollutant Removal Efficiency} = \frac{\text{Inlet [Nutrient]} - \text{Outlet [Nutrient]}}{\text{Inlet [Nutrient]}} \times 100 \quad \text{.............................. 01}$$

## 3. Result and Discussion

### *A. Water Quality Analysis*

***Phosphate -phosphorus ($PO_4^{-3}$-P)***

Phosphorous occurs as phosphate in organic and inorganic compounds in the wetlands. Removal of phosphorous from the soil solution is mainly occurred by plant uptake and retention/adsorption into soil colloids. Phosphorous uptake by macrophytes is usually highest during the initial plant growth before the maximum growth rate is attained. As soluble N and particularly P are usually considered to be key elements in water pollution, which normally leads to blue-green algal bloom in inland waterways and lakes, the removal of these elements by vegetation is the most cost-effective and environmentally friendly method of controlling algal growth (Vymazal, 2007). In this study, $PO_4^{-3}$-P (ppm) concentration of influent and effluents was measured during two weeks interval removal efficiencies were calculated (Fig.3).

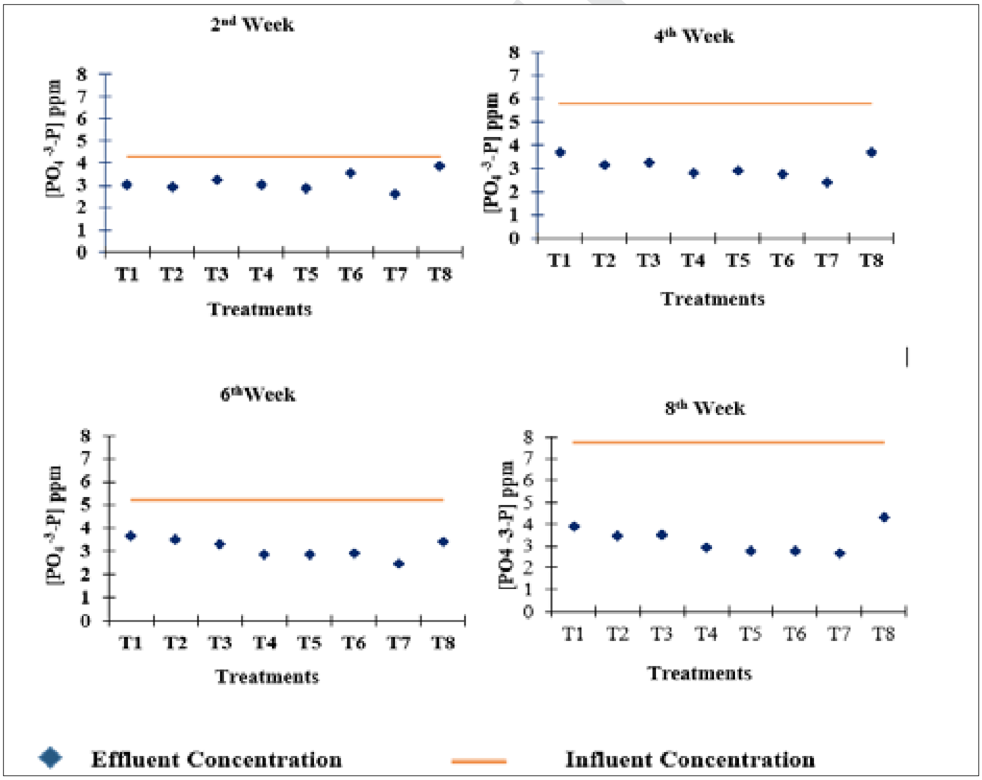



**Fig.2:**
**Measured $PO_4^{-3}$-P concentration of the influents and the effluents in two weeks intervals**

The average $PO_4^{-3}$-P concentration of inlet was 5.75 ppm. During the treatment process, effluent $PO_4^{-3}$-P concentration has been decreased (figure 4.5)every two weeks. Starting with the lowest REs, all the treatment combination have been enhanced their REs during the remediation process. At the end of the two months of the experimental period, significantly ($p<0.05$) highest RE (65%) was recorded in T7 or Kangkung * Kohila *Vetiver plant combination. Combined dense root systems of Kangkung, Kohila, and Vetiver could be the reason for the highest P pollutant removal efficiency with Kangkung * Kohila *Vetiver plant combination. Developed root systems provide a surface to microbial growth which helps to filter solid that may increase pollutant removal efficiency. Phosphorous accumulation take place in plant bodies and soil, as a result of biological uptake and chemical bounding (Cheng *et al.,* 2002).

| | | | |
|---|---|---|---|
| **T1** | **Vetiver** | **T5** | **Vetiver + Kangkung** |
| **T2** | **Kohila** | **T6** | **Kohila+ Kangkung** |
| **T3** | **Kangkung** | **T7** | **Vetiver + Kohila + Kangkung** |
| **T4** | **Vetiver + Kohila** | **T8** | **Control** |

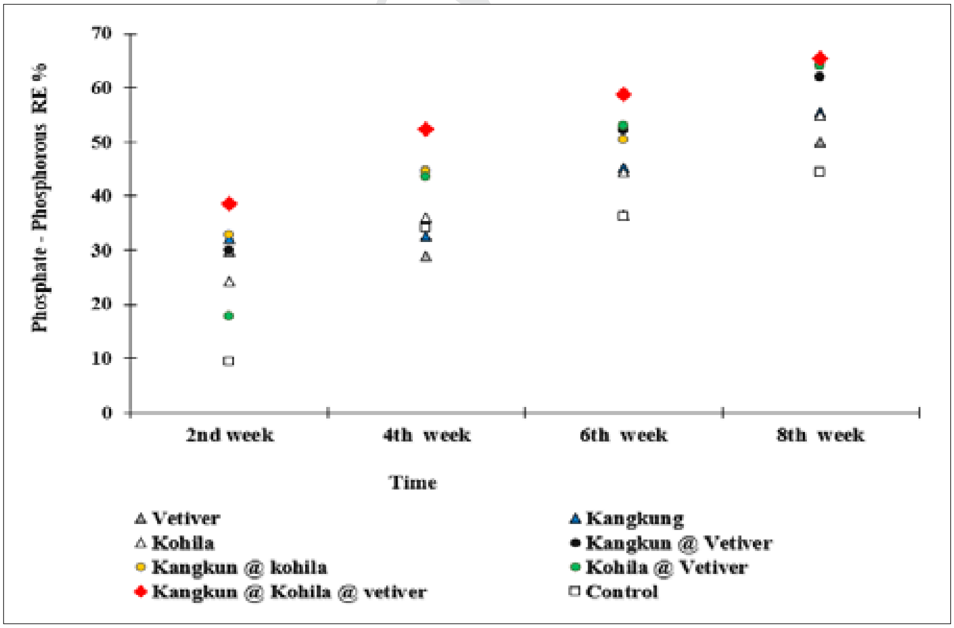



**Fig.3 :**
**Removal Efficiencies of $PO_4^{-3}$-P with Time (%).**

### *Ammonium -nitrogen ($NH_4^+$-N)*

In constructed wetland systems, N pollutant removal efficiency is mainly depending on vegetation, hydraulic retention time, wastewater drawdown, microorganisms, and the type of the media. Similarly, N can be removed by assimilation through plants, adsorbing to the substrate, or with the de-nitrification process (Zhang *et al.,* 2009). In this study, the average $NH_4^+$-N concentration in influents was 2.3ppm. Effluent concentration was slowly decreased with time as shown in fig. 4. However, in every two weeks, effluents were recorded low $NH_4^+$-N concentrations compared to the influent.

Fig. 5 shows the REs of $NH_4^+$-N concentration of the influents and the effluents in two weeks intervals. Removal efficiencies were gradually increased in all the tested treatments. Kangkung *Kohila * Vetiver plant combination recorded significantly ($p$<0.05) highest RE (62%) at the end of the two months sampling period.

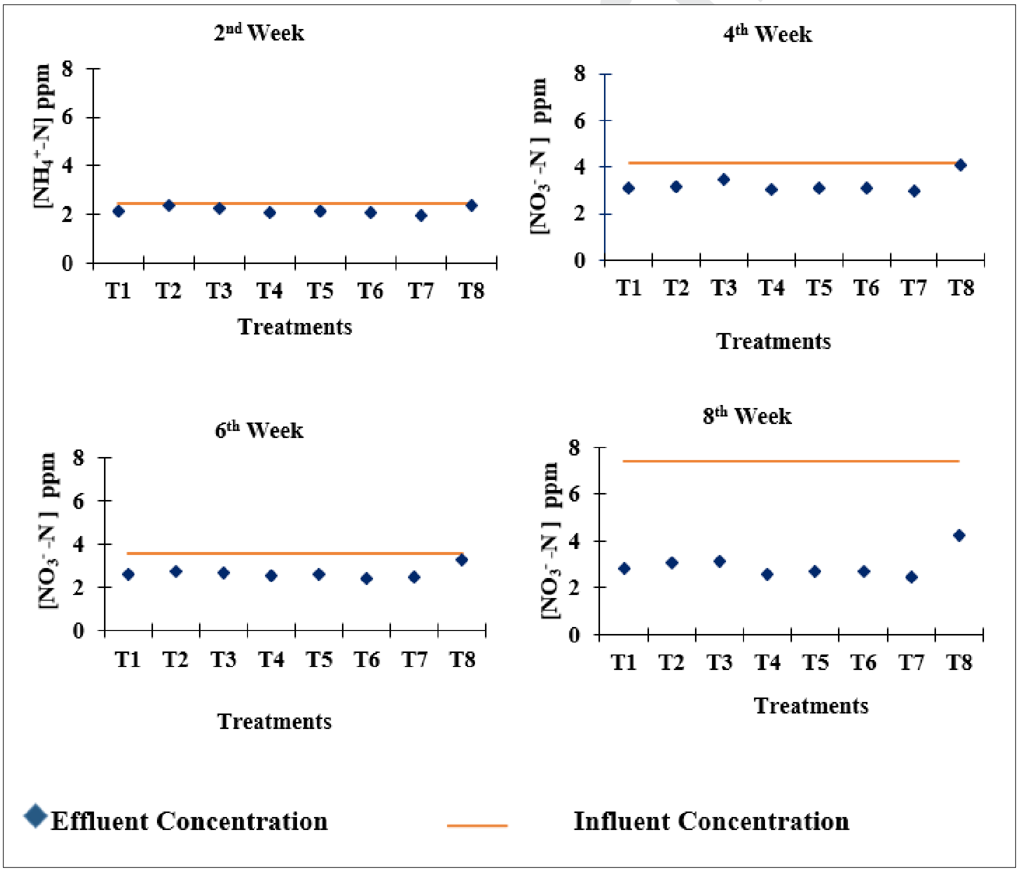
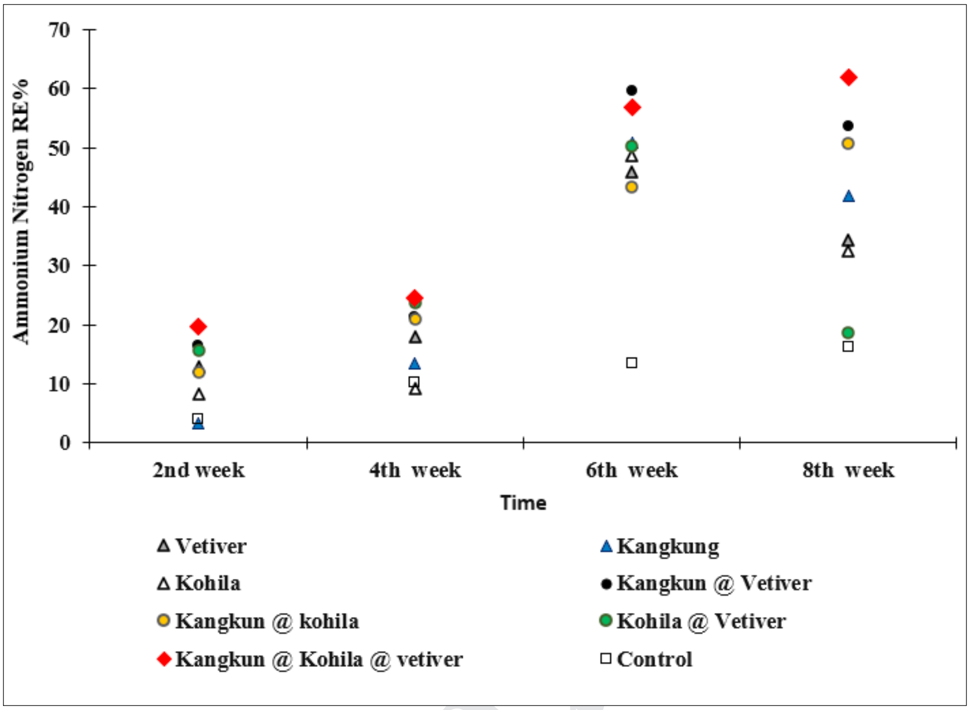



**Fig. 4:**
**Variation of $NH_4^+$-N concentration of the influents and the effluents in two weeks intervals.**




| | | | |
|---|---|---|---|
| **T1** | **Vetiver** | **T5** | **Vetiver + Kangkung** |
| **T2** | **Kohila** | **T6** | **Kohila+ Kangkung** |
| **T3** | **Kangkung** | **T7** | **Vetiver + Kohila + Kangkung** |
| **T4** | **Vetiver + Kohila** | **T8** | **Control** |

**Fig. 5:**
**Removal Efficiencies of $NH_4^+$-N with Time (%).**

## Nitrate - nitrogen ($NO_3^-$ - N)

Figure 6 illustrates the $NO_3^-$-N concentration in influent and effluents in two weeks intervals. The average influent $NO_3^-$-N concentration was 4.7 ppm, During the treatment process $NO_3^-$-N concentrations of effluents were decreased compared to influents. It has been estimated that wetlands may remove between 70% and 90% of Nitrogen (N) entering the system (Bachand and Horne, 1999).

At the end of the two months remediation process inside the wetlands system, T7 or three plant combination was performed highest compared to other plant combination (Figure 07). The combined effect of Kangkung *Kohila * Vetiver was efficient in removing significantly ($p<0.05$) the highest amount of $NO_3^-$ - N pollutant (66%) through their effective root combination.

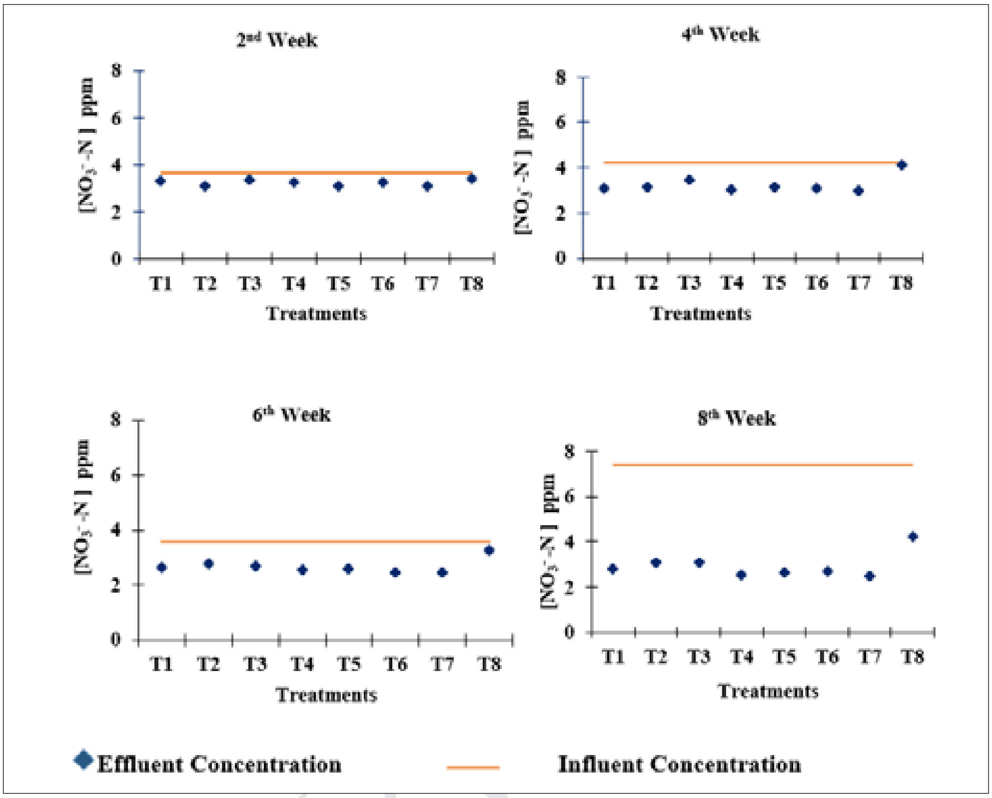
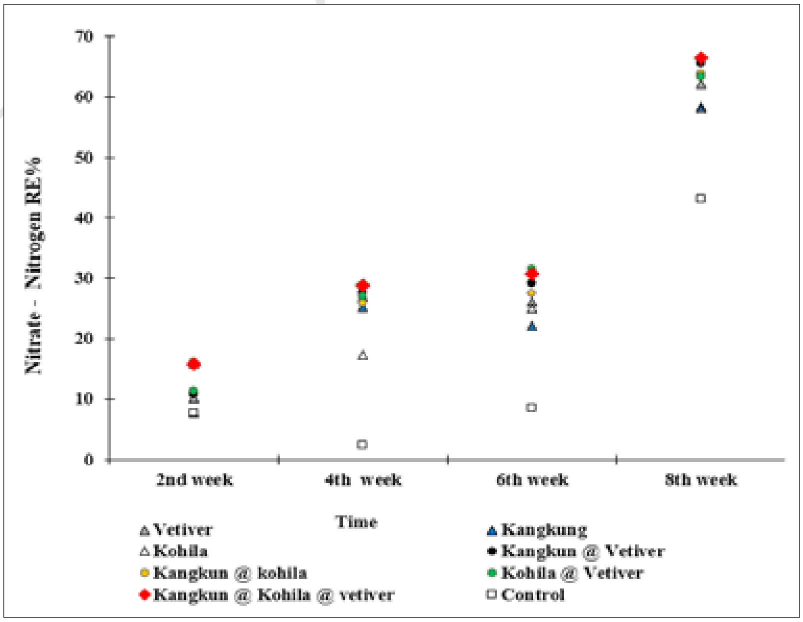



**Fig. 6:**
**Variation of $NO_3^-$ - N concentration of the influents and the effluents in two weeks intervals.**



| | | | |
|---|---|---|---|
| **T1** | **Vetiver** | **T5** | **Vetiver + Kangkung** |
| **T2** | **Kohila** | **T6** | **Kohila+ Kangkung** |
| **T3** | **Kangkung** | **T7** | **Vetiver + Kohila + Kangkung** |
| **T4** | **Vetiver + Kohila** | **T8** | **Control** |

**Fig. 7:**
**Removal Efficiencies of $NO_3^-$ - N with Time (%). (include treatment numbers to the legend)**

### *Total Dissolve Solid(TDS) and pH*

The reaction of influents and effluents were not much varied throughout the treatment process. As shown in figure 8, both influents and effluents were ranged between the permissible levels for the irrigation water standards of 6.5pH - 8.5pH. No hazardous effect was recorded in plants or soil when using irrigation water with the aforementioned pH range (Ayers and Wescot, 1985).

Total Dissolved Solids (TDS) indicates the amount of water soluble compouds disssolved in water. During thestudy period, TDS of the effluents were remained in equal or lower level compared to the TDS of the influent (Figure 09). It may be due to the action of filtration by root systems of plants and filtration by soil layer (Gopalan *et al*., 2009). Both influent and effluent TDS values were well below the 2000 mg/l the maximum permissible level for irrigation (National Environmental Regulation, 2008).

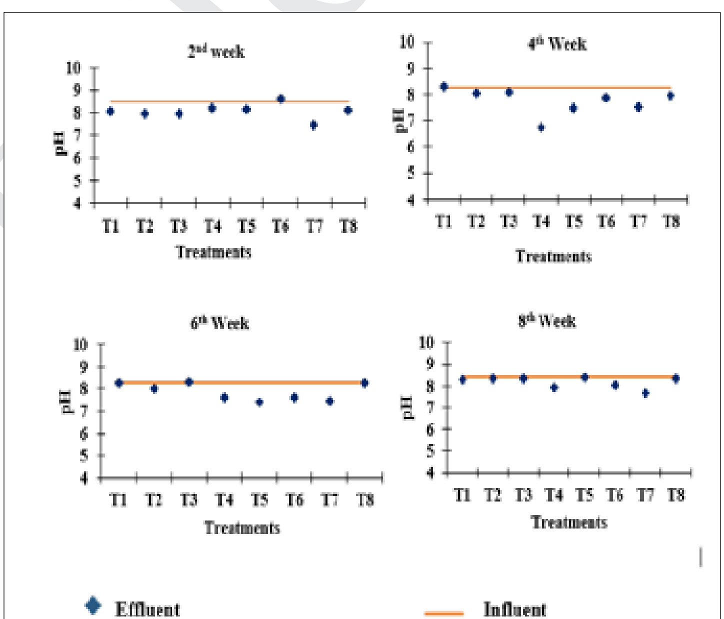



**Fig. 8:**
**Variation of the pH of influents and effluents**

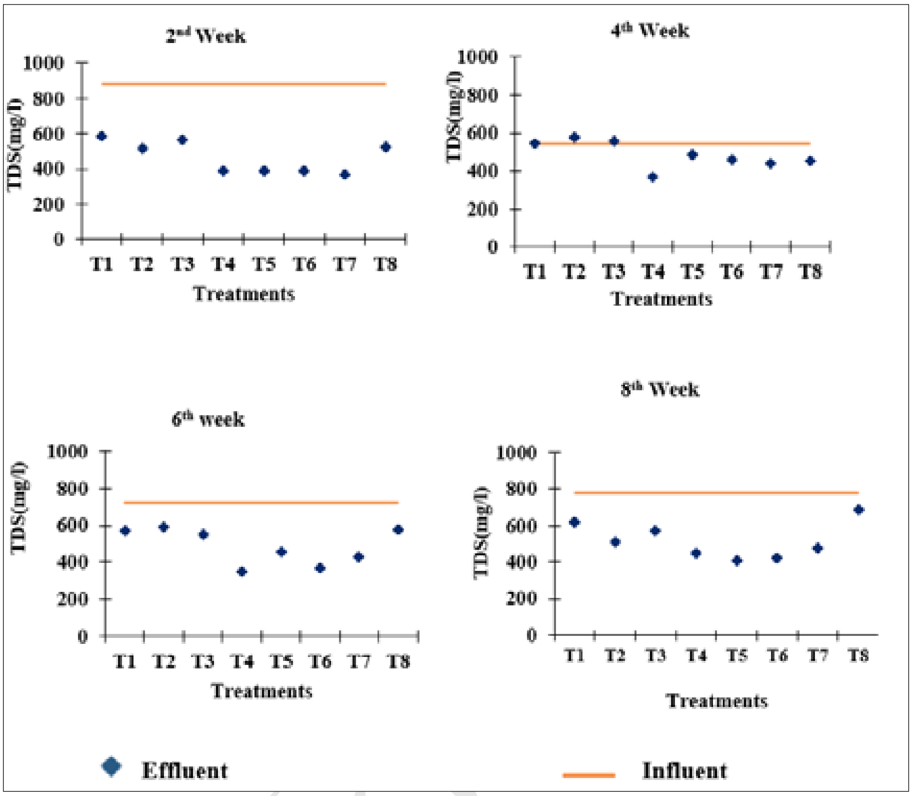


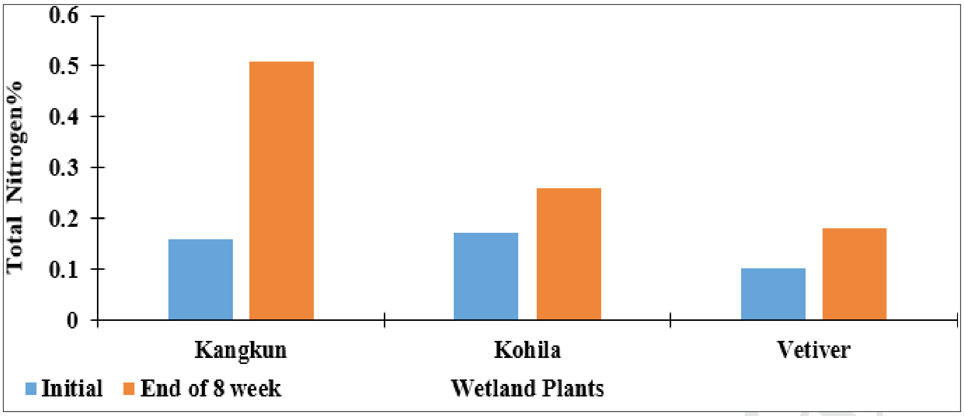

**Fig.9:**
**Variation of TDS of influents and effluents**

***B. Plant Analysis***

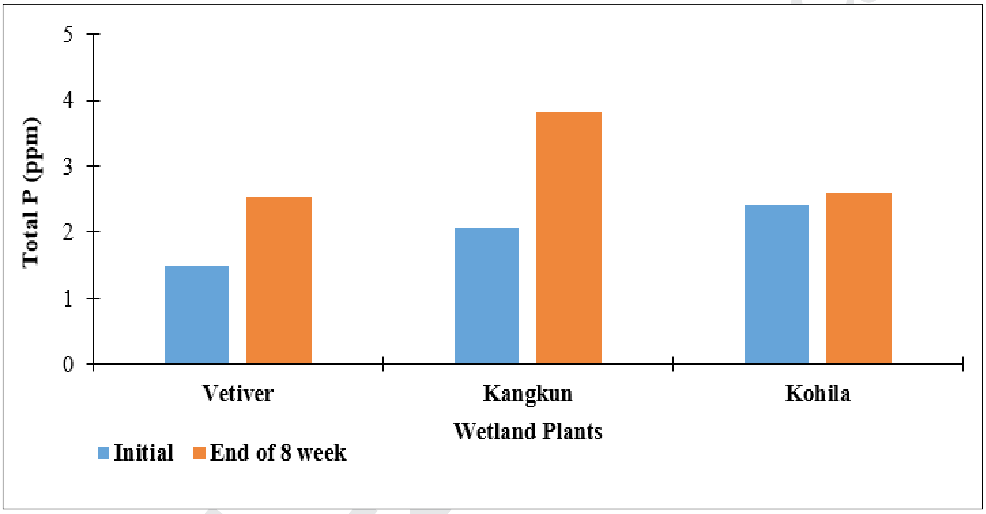
***Total N and P contents of Wetland plants***

The activity of the roots of the wetland plants is dominant in the phytoremediation process. The root uptake N and converts inorganic N into organic compounds (Vymazal, 2007) during the phytoremediation. Figure 10 illustrates the total N of wetland plants measured before the experiment and at the end ( $8^{th}$ weeks) after experiment. It clearly revealed that all the wetland plants used in the experiment significantly contributed to N pollutant removal by accumulating N in plant biomass.

Wetland plants remove aquatic pollutants through a complex variety of biological, physical, and chemical mechanisms, including adsorption, precipitation, sedimentation, and microbial transformation ( Cheng *et al.,* 2002). A significant P accumulation in plant tissues was also observed when comparing plant P level at the initial stage and the end of the experiment period (Figure 11).




(a)




(b)

**Fig. 10:**
**Comparison of total N (a) and P (b) contents of the wetland plants before the experiment vs end of the experiment.**

## 4. Conclusions

All the wetland plants recorded increasing pollutant removal efficiencies throughout the monitoring period. Combinations of all three plant species showed higher performance in removal of $NH_4^+$-N, $NO_3^-$ - N, $PO_4^{-3}$-P compared to two plants combinations and single plants. It may probably due to the highest root density and variation of root depths in three plant combinations of Kangkung, Kohila, and Vetiver. Overall, it can be concluded that small-scale CW units are a viable technology for greywater treatment at the domestic level with the combination of the tree plant species;Kangkung, Kohila, and Vetiver plants.

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# Local community perception to participate in agro-tourism in *Palugaswewa* Tank Cascade System

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## Abstract

Sri Lanka as an agricultural country has many potentials to promote agro-tourism aiming for sustainable rural agricultural development. Nonetheless, the community perception of participation for agro-tourism is not at a satisfactory level. Hence, the study explored the potential and perception of the local community to participate in sustainable agro-tourism activities in *Palugaswewa* Cascaded Tank Village System which was recently nominated as a world heritage. A simple random sampling method was used to select 234 respondents. Collected data through field surveys, focus group discussions and key personnel interviews were analyzed qualitatively and quantitatively. Logistic regression results revealed that gender [Odds Ratio (OR)=2.849], primary occupation (OR=3.284), engaging in tourism activity (OR=6.333), awareness about the agro-tourism activities in *Palugaswewa* (OR=8.106) are significantly ($p<0.05$) affecting the participation for agro-tourism by the villagers. The factor analysis revealed that social, social welfare, environmental, and land associated factors are significantly ($p<0.1$) affecting community perception on agro-tourism. According to the thematic analysis, wild animal tours, nearby *Habarana* and *Ritigala* tourism hotspots, traditional agricultural practices, available ancient ruins in the area, and infrastructure facilities are some potentials and possible ventures for agro-tourism in the area. Hence, the study concluded that there is a potential for introducing a sustainable agro-tourism plan in *the Palugaswewa* cascade in Sri Lanka.

**Keywords**: *Agro-tourism, Cascaded tank village system, Potentials, Social welfare*

## 1. Introduction

Tourism comprises the activities of persons traveling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business, and other purposes (James, 2004). Agro-tourism, farm tourism, or agricultural tourism is the process of attracting visitors and travelers to agricultural areas, mainly for educational and recreational purposes. There are economic difficulties and changes in the farming and livestock industries in many countries in the world. Many farmers especially those who have small-scale, family-owned farms have understood the necessity of supplement their agricultural business model. So, they find new ways of generating income. Agro-tourism can contribute to the overall income, cash flow, and profitability of a farm by providing alternative income via farm products, and farming activities (Malkanthi & Routry, 2011). For example, agro-tourism in Italy showing the agricultural and ecological education events has supported the protected areas from agricultural development. In short, the perception of agro-tourism progression covers the views of tourists' increase of awareness and comprehension on environmental protection and agricultural inhabitants' quality of life improvement particularly in developing countries in which agriculture is yet an important strategy in rural development. Also, China reports providing food for millions of visitors on an annual basis in Shanghai (Awan et al., 2016).

Agro-tourism is significantly different than mass tourism. At present, tourists expect things rather than pleasure from a tour. Some like to get farming experiences, learn about farming, increase their health condition, identify rural culture, as well as pleasure. So nowadays, there is a good demand for agro-tourism in the world. Also, agro-tourism is a good alternative to reduce the agricultural risk of farmers (Maetzold, 2002). Many developing countries have embraced agro-tourism as a strategy for rural development through the intention of accomplishing the well-being of the farming community in these countries. Taiwan and the Philippines are the major agro-tourism destinations in the Asian region. In these countries, agro-tourism activities were developed according to government policies (Rambodagedara et al., 2015).

Moreover, tourism is one of the largest and fastest-growing industries in the world economy. In Sri Lanka, the tourism industry is the fourth highest foreign exchange generator of the economy. According to the Sri Lanka Tourism Development Authority (SLTDA, tourist arrivals increased 14% in 2016 to a record 2.05m visitors. This was up from 1.798m in 2015.

Furthermore, agro-tourism is a new dimension of alternative tourism development to traditional mass tourism. It will have great potentials with various opportunities to develop the Sri Lankan tourism industry sustainably. Agro-tourism is a part of rural tourism and it relates to tourism on farms, plantations, and home gardens. Agriculture has always been deeply related to the social, cultural, and economic aspects of Sri Lankan history. Looking at the current situation in Sri Lanka, it is not specifically recognized for agro-tourism and is a part of the tours, not the focus. The government promotion of the field is relatively low (Wijewickrama, 2011). In the Sri Lankan context, Agro Technology Parks are established with the objectives of agriculture extension, education, and agro-tourism in Sri Lanka by the Department of Agriculture. The first Agrotechnology Park was formed in *Gannoruwa* in the Kandy district. The second Agrotechnology Park was established in the Hambantota district adjoining *Bataatha* government farm (Department of Agriculture, 2018). In these agricultural farms, agricultural activities ranging from hi-tech agriculture to traditional agriculture. That is demonstrated for the visitors who came to these places. It also strongly focuses on providing information to farmers, school children, and the general public, provide education and training mechanisms, demonstrate the recommended crop varieties and technologies, and edible landscaping consisting of tropical crops (Department of Agriculture, 2018).

According to Malkanthi & Routry (2011), availability of significant number of farmers with private properties, presence of attractive agricultural landscapes including unique features for most of the areas, availability of beautiful natural landscapes with clean and healthy environment, presence of knowledgeable and energetic farming community, availability of significant level of family labor, presence of traditional farming activities including Chena cultivation, organic farming, availability of traditional cultural activities including various livelihoods, Sri Lankan cuisine, availability of preserved environment due to the absence of industrial activities, availability of a number of tourist attractive locations, presence of mutual co-operation of farmers with other organizations in these areas, availability of a large number of unemployed youth that an employee in the agro-tourism sector, initiation of emphasis on sustainable rural tourism development by the government, gradual increase in the demand for agro-tourism by the visitors are some possibilities to introduce agro-tourism for Sri Lanka.

### ***Palugaswewa*** **Tank Cascade System**

*Palugaswewa* cascade system contains 78 miner reservoirs and *the Udakadawala* tank is the main and largest one. This cascade system is started 67.5 km far from the *Udakadawala* tank. The establishment of these cascade systems has begun in the 6$^{th}$ century (Piyadasa et al., 2012). There are varying sizes of 11 tanks found within the village. The cascade consists of two villages that cover an area of nearly 1,300ha namely, *Palugaswewa* and *Udakadawala*. Among them, 156ha are paddy lands, which feed on these tanks. Those paddy lands are cultivated by 244 farmers. There are two tanks renovated recently from their abandoned state. Provision is kept for the development of traditional components such as *Kattakaduwa*, *Gasgommana*, and *Kiulela* (drainage way) in these tanks. The other tanks had been in presence in working condition for a long time. They have been improved in recent times by the government. Some tanks are very small, most probably must have been constructed to trap sediments. The dominant land uses of the site include tanks (including bund, *kattakaduwa*, and *gasgommana*), streams, lowland paddy fields, home gardens, chena, forests, and scrublands.

*Palugaswewa* cascade system is one of the cascade systems, which is nominated as a world heritage in 2018 by the Food and Agricultural Organization (FOA, 2018). It contains 78 minor reservoirs and the *Udakadawala* tank is one of the largest tanks. In past, this cascade system played a major role in the human lifestyle. Because villagers got water for every purpose from these tanks and their occupations were combined with this cascade system. Not only that, villagers were assigned various responsibilities regarding the tanks. Villagers respected and conserved the tank system. If not, they were punished by the village leader called "*Gamarala*". At present, there are no such rules, regulations, or responsibilities among villagers about the cascade system. Therefore, at present, it has faced a tragic condition (Piyadasa et al., 2012).

However, the continuation of the Cascaded Tank-Village System is threatened by the poor income of farmers in this area as a result of extracting natural resources to fulfill their day-to-day life needs (FOA, 2018). But now it is becoming a problem. Because at the present people over utilizing natural resources in this system. They cut trees in "*wew thawulla*" for economic purposes. So, there are only a few trees to protect the "*ellanga* system". A lot of people in this village were involved in agriculture as their occupation. They have mainly cultivated paddy as a monoculture. There are some natural disasters like droughts and floods. Due to that their crops get damaged. Most of them haven't any other option than agriculture. They face high agricultural risk due to the absence of risk diversification methods. Moreover, the young generation dislikes engaging in agriculture. They migrate to urban areas. This reduces the population of the next generation resides in the village. It can affect badly to protect this world heritage.

It is the responsibility of both villagers and the whole people in our country to protect this cascade system. Creating job opportunities to protect this ecosystem is a major responsibility of authority. As *Palugaswewa* is located close to *Habarana* (area of tourist attraction), there is a possibility to introduce agro-tourism as a solution for the unemployment problem. As well as a measure of conservation of this cascade system. A lot of tourists may come to this area to visit this world heritage. Villagers can involve in agro-tourism activities to earn income. Then automatically cascade system is conserved. Agro-tourism can create job opportunities especially for youth, and then they will remain within the village. Mass tourism cause to spread of various malpractices and those can affect badly to the village culture. Sometimes drugs and bad habits like smoking can invade villages with tourists. Therefore, most young people in villages might addict to use those things and disrupt their education. As well as some tourists come to villages and extract natural resources and bring them to their countries. That destroys the natural resources of the village. However, there is no such harm through agro-tourism approaches like the niche tourism method. It creates job opportunities for men, women, and youth. It uplifts the livelihood of villagers. Then educational facilities, infrastructures, health services, awareness programs, etc. will improve within the village. Finally, villagers can spend their lives happily without causing any disturbance to the environment. Hence, the study attempts to explore the perception of the local community and the potential to introduce agro-tourism in the *Palugaswewa* tank cascade system.

## 2. Methodology

### Study Areas and Target Population

The study was conducted in the *Palugaswewa* cascade system which is located at Anuradhapura district, North Central province. Longitude is 80° 32’ 0” E and Latitude is 7°


**Map 1: *Palugaswewa* cascade system**
**Source: Google earth, 2020**

55' 0" N. There are 15582 populations in *Palugaswewa* Divisional Secretariat (DS) division (Census of Population and Housing of Sri Lanka, 2012). There are 16 *Grama Niladhari* (GN) divisions in *Palugaswewa*. Among them, *Palugaswewa* and *Horiwila* GN divisions were selected as target populations (Map 1).

**Sample Size and Sample Selection**

Table 1 shows the distribution of the sample within the study area. There is 1277 population in the *Horiwila* GN division and a 1070 population in the *Palugaswewa* GN division. Household head lists maintained by the *Grama Niladhari* divisions were the sampling frame. A representative sample for both *Grama Niladhari* divisions was selected which cover 10% of the total population in each GN division. A simple random sampling method was used to select the 234 respondents using a household head list in each GN division.

**Table 1: Distribution of sample size**

| GN Division | Population | Sample Size |
|---|---|---|
| Horiwila | 1277 | 127 |
| Palugaswewa | 1070 | 107 |
| Total | 2347 | 234 |

***Source:* Field survey data, 2020**

**Data and Data Collection**

Both primary data and secondary data were used in this study. Demographic characteristics of respondents such as age, education, occupation, ethnicity, religion as well as their perception to participate, expected economic, social, cultural, and environmental impacts of agro-tourism plan and factors contributing to an inclination to participate were assessed during the primary data collection. Further, information on available tourism destinations around the area, tourist statistics such as peak seasons of tourism, preferred destinations, nativity of tourist, as well as policies and other regulations, etc. were collected from secondary data.

Mainly, primary data were collected using a pre-tested structured questionnaire, key person interviews, field observations, and focus group discussions. The key personal interviews and focus group discussions were completed with social activators, Grama Niladhari, chief monk of the temple, school principal, youth, government sector servants, private sector servants, and members from NGOs. Data from the tourism department, census and statistics, internet, newspapers, bulletin, and cultural centers were used in obtaining secondary data.

**Data Analysis**

Data were analyzed using both qualitative and quantitative techniques. Data obtained from the questionnaires were grouped based on the research questions and were analyzed using descriptive statistical methods such as mean, percentages, frequencies, standard deviation, etc., and quantitative statistical methods such as factor analysis and logistic regression analysis.

Descriptive statistics were used to identify potentials and possible ventures for the implementation of the agro-tourism development plan. Moreover, Different parameters of economic, socio-cultural, and environmental were considered to uncover the attitudes and perceptions of the local community to involve in agro-tourism. Factor analysis was used to analyze those parameters and the attitudes and perception of the local community to involve in agro-tourism.

Logistic regression was used to analyze the factors contributing to community inclination (Table 2) to participate in agro-tourism.

Equation for logistic regression,

$$\ln Y = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \ldots\ldots\ldots\ldots \beta_n \ln X_n + \text{error}$$

Y = Probability of inclination to participate in agro tourism

$\beta_0$ = Intercept

$\beta_1$, $\beta_2$, $\beta_n$ = Coefficient of variables

$X_1$, $X_2$, $X_n$ = Independent variables

**Table 2: Description of social, economic, and ecological variables used in the logistic regression**

| Variables | Description | Measurement |
|---|---|---|
| Social | Age | Years (in number) |
| | Gender | Male, Female |
| | Ethnicity | Sinhala, Tamil, Muslim, Other |
| | Religion | Buddhism, Hindu, Catholic, Islam, Other |
| | Educational level | Years (in number) |
| | Housing condition | Permanent, Semi-permanent, Improvised |
| | Health status of the family | Presence of non-communicable diseases among family members |
| | Organizational membership | Yes, No |
| | Access to public infrastructure | Nearest distance from the house to DS office (Km) |
| | Size of the household | In number |

| | | |
|---|---|---|
| Economic | Occupation | None, Farming, Government Sector, Private Sector, Self-employment |
| | Average income | In number |
| | Unemployment of the household | In number |
| | Land size | Number of acres |
| | Secondary occupation | Yes, No |
| | Capability of handcrafting | Yes, No |
| Ecological | Concern about environmental protection | Yes, No |
| | Engaging agricultural activity | Yes, No |
| | Harvesting resources from the forest | Yes, No |

***Source:* Field survey data, 2020**

Further, the thematic analysis was used to identify the potentials and possible ventures for implementation of Agro-Tourism in the Palugaswewa Tank Cascade System.

## 3. Results and Discussion

### Demographic Characteristics of Respondents

According to the data analysis, the majority of respondents belonged to the 41-60 years age category. After this, most respondents belonged to 21-40- and 61-80-years categories

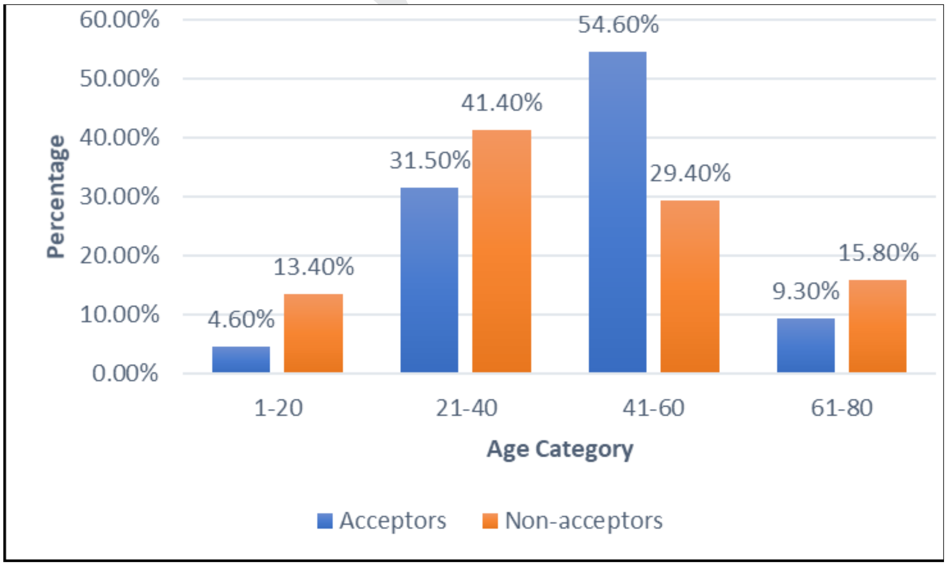


**Figure 1: Age categories of respondents**
***Source:* Field survey data, 2020**

respectively. Less number of respondents represented in 1-20 years age category (Figure 1). Further, the mean age of acceptors and non- accepters were 43 and 39 years respectively. The minimum and maximum age levels of acceptors were 18 years and 74 years. At the same time, the minimum and maximum age levels of non-acceptors were 16 years and 80 years (Table 3). The average age of respondents was 42 years and the minimum and maximum ages of respondents were respectively 16 years and 80 years. Furthermore, many of the respondents (63%) were female in the study area.

**Table 3 Age distribution of the respondents**

| Group | Mean | St. Dev. | Minimum | Maximum |
|---|---|---|---|---|
| Acceptors | 43 years | 13.75 | 18 | 74 |
| Non-acceptors | 39 years | 17.30 | 16 | 80 |

***Source:*** **Field survey data, 2020**

According to the results, 186 respondents had obtained education up to the secondary education level. It represented 80% of the total respondents. Further, 11% of respondents had schooled up to primary education and 8% of respondents received tertiary education category. Only 1% of respondents had finished their higher education. Most of the respondents in the study area had received a satisfactory education (Figure 2).

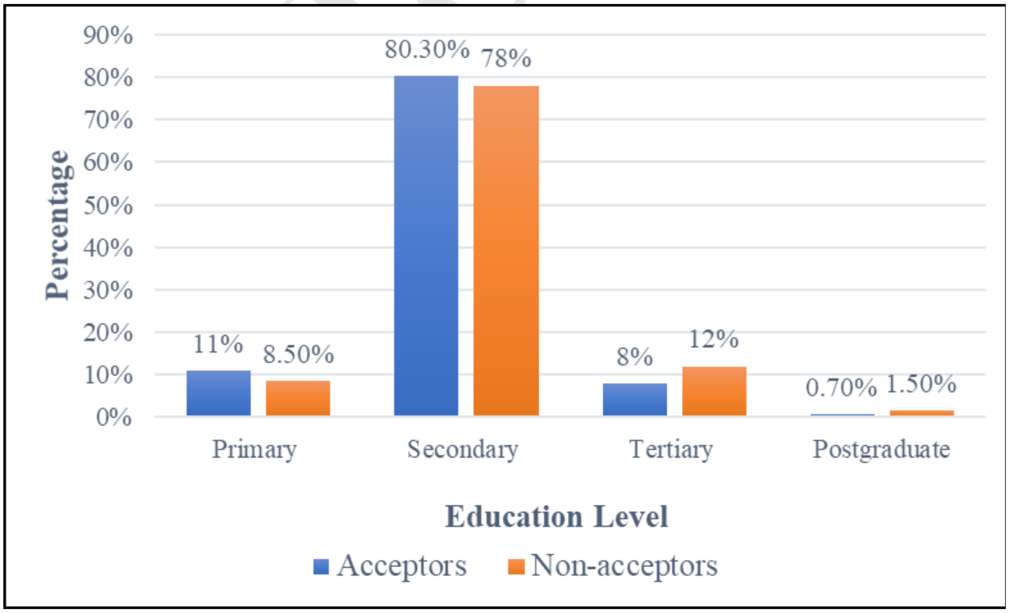


**Figure 2:**
**Education level distributions among respondents**
***Source:*** **Field survey data, 2020**

According to the data analysis, the majority of respondents belonged to the married category. After that, most respondents belonged to single and widowed categories respectively. Less number of respondents represented the divorced category (Figure 3).

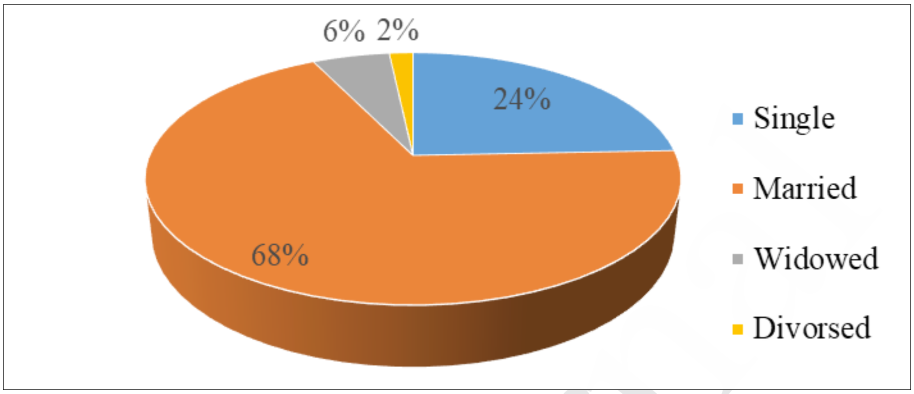


**Figure 3: Marital statuses among respondents**
***Source:* Field survey data, 2020**

According to the results, the highest number of respondents (22%) worked as daily waged employees as their primary occupation. Of all respondents, 19% were involved in business, 17% involving in self-employment, and 14% involving the private sector. The least number of respondents (3%) not involve in any occupation (Figure 4). Moreover, 77% of respondents are not involved in any secondary occupation. At the same time, 8.9% of respondents are involved in farming as a secondary occupation. The least number of respondents (1%) are involved in the government sector, private sector, and business as their secondary occupation. Also, 1% of respondents are involving in studies as their secondary occupation (Figure 5).

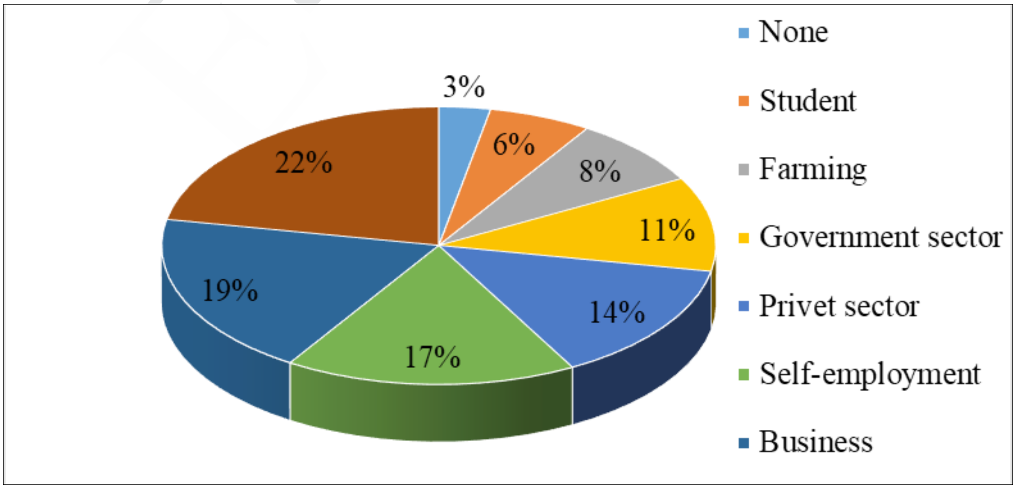


**Figure 4: Primary occupations of respondents**
***Source:*Field survey data, 2020**

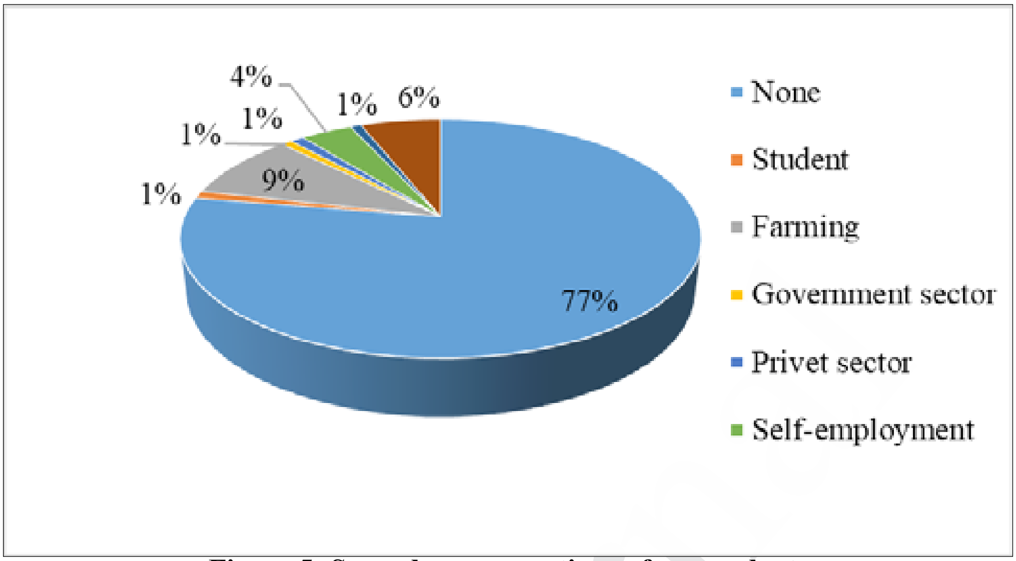


**Figure 5: Secondary occupations of respondents**
***Source:* Field survey data, 2020**

Further, the results of the descriptive analysis revealed that the average household size of the sample was four members. Of all respondents 77.7% were healthy and 22.2% had diseases like kidney failures. The average income level of respondents was Rs. 22768.55. Therefore, they had several economic problems. They can involve in an agro-tourism plan as an alternative income source to cover the immediate household expenditures. Some women can make handicrafts. Then, they can make them and can sell them to tourists who come to the village. It creates extra income for villagers.

Several reasons were provided by respondents for the acceptance of the agro-tourism plan. Conserve tank cascade system, create job opportunities, create extra income source, develop public services and village agriculture, and improve quality of livelihood of villagers are reasons to accept the agro-tourism plan. Deteriorate village culture, disturb a calm environment, waste generation, disturb wild lives, expand drugs in the village and disturb the traditional livelihood of villagers are the reasons for non-acceptance of this plan.

**Potentials and Possible Ventures for Implementation of Agro-Tourism in *Palugaswewa* Tank Cascade System**

According to the thematic analysis, there are several potentials and possible ventures, which are suited to introduce agro-tourism in the *Palugaswewa* tank cascade system. They can divide into three categories such as environmental, cultural, and economic. The main environmental potential is the tank cascade system in this area. Other than that, *Habarana* and *Ritigala* tourism hotspots are located near *Palugaswewa* and there are various wildlife species on this site. Ancient ruins in *Galada Purana viharaya*, rural village, traditional agriculture, and medicinal practices are some of the cultural potentials in the *Palugaswewa* area. Economic potentials are available lands, *Palugaswewa* railway station, better road facilities, and the main occupation of villagers is agriculture. They conduct several traditional festivals like *aluth sahal mangallaya, pullayar danaya,* and *gammadu shanthikarma.* Also, some villagers can make handicrafts using natural materials like *pan* (Figure 6).

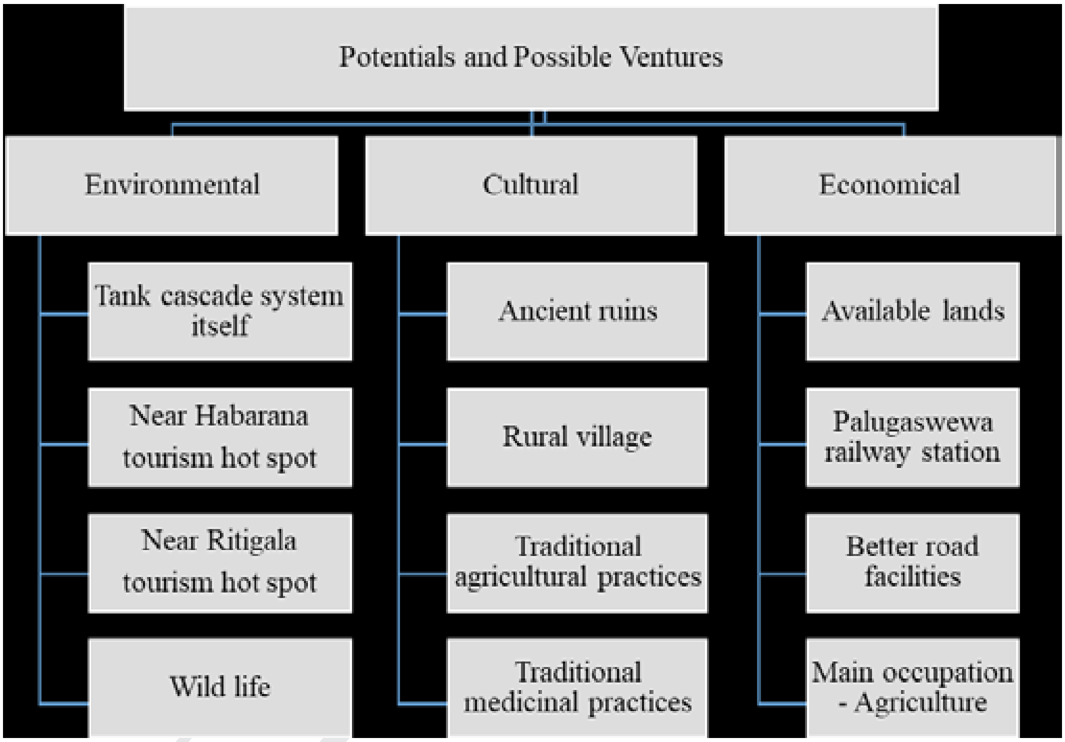


**Figure 6: Potentials and possible ventures for implementation of agro-tourism**
***Source:* Field survey data, 2020**

**Attitudes and Perception of the Local Community to Involve in Agro-Tourism in *Palugaswewa* Tank Cascade System**

Results reviewed that 65% accepted introducing an agro-tourism plan to the cascade while 35% not accepted introducing an agro-tourism plan. There were different attitudes and perceptions of villagers about introducing agro-tourism to the *Palugaswewa* cascade. Factor analysis was done to identify the attitudes and perceptions that affect to acceptance of the agro-tourism to the cascade Following figure shows (Figure 7) the result of the factor analysis.

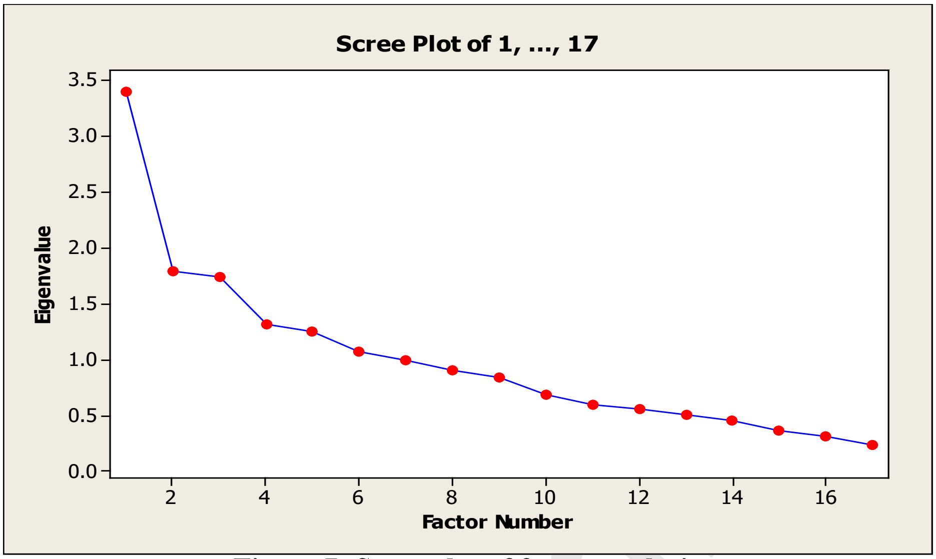


**Figure 7: Scree plot of factor analysis**

***Source:* Field survey data, 2020**

According to the scree plot, 9 variables (Table 4) were significantly affected by the perception of villagers to accept the agro-tourism plan. Improves the quality of public services, improves the quality of village life condition, increases traffic jams, increases crowding, damages village culture interrupts quiet life in the village, improves the image of the village, increases crimes and social problems, increases the land value of village are those variables.

**Table 4: Rotated factor loadings and communalities**

| Variable | F 1 | F 2 | F 3 | F 4 |
|---|---|---|---|---|
| Improve the quality of public services | -0.016 | **0.829** | -0.055 | -0.036 |
| Improves quality of villages life condition | -0.092 | **0.752** | -0.095 | 0.000 |
| Increases traffic jam | 0.226 | 0.006 | **0.792** | -0.103 |
| Increases crowding | 0.201 | -0.135 | **0.797** | -0.033 |
| Damages village culture | **0.720** | -0.117 | 0.170 | -0.082 |
| Interrupt quiet life in the village | **0.654** | -0.081 | 0.079 | 0.158 |
| Improves the image of the village | 0.095 | 0.509 | 0.074 | **0.113** |
| Increases crimes and social problems | **0.641** | -0.035 | 0.030 | 0.012 |
| Increases the land value of the village | 0.271 | -0.032 | 0.220 | **0.146** |

***Source:* Field survey data, 2020**

Based on the factor close correlation of factor loading values, those variables were categorized into four factors namely social factors, social welfare factors, environmental factors, and land associated factors (Table 5).

**Table 5: Factor analysis results**

| | |
|---|---|
| Social factors | **Damages village culture**<br>**Interrupts quiet life in the village**<br>**Increases crimes and social problems** |
| Social welfare factors | Improves the quality of public services<br>Improves the quality of village life condition |
| Environmental factors | Increases traffic jams<br>Increases crowding |
| Land associated factors | Improves the image of the village<br>Increases the land value of the village |

***Source:*** **Field survey data, 2020**

According to Kunasekaran et al., (2011) in Malaysia found that environmental impacts, accessibility, economic benefit, crowding, entrepreneurial knowledge, awareness, socio-cultural benefits, constraints, and land issues are the factors affecting the perception scale on agro-tourism in Cameron Highlands, Malaysia. Another similar study was done by Eshliki and Kaboudi, 2012 that environmental destruction, social and cultural effects, economic effects, water and coast pollution, life quality improvement are the factors affecting to community perception of tourism impacts and their participation in tourism planning in Ramsar, Iran.

**Factors Contributing to Community Inclination to Participate in Agro-Tourism in *Palugaswewa* Tank Cascade System**

According to the logistic regression results gender, primary occupation, engagement in tourism activity and awareness of upcoming agro-tourism plan in *Palugaswewa* are the factors contributing to community inclination to participate in agro-tourism (Table 6).

When the community enhances their awareness of the upcoming agro-tourism plan in the *Palugaswewa* area people who reject the proposed project more likely to accept the agro-tourism development plan (OR:8.106). Therefore, conducting effective awareness programs will be advantageous for the stakeholders. Further, results prove that odds of accepting an agro-tourism plan is higher for people who not have primary occupation (1) (OR=3.284), student (2) (OR=0.176), Private sector (5) (OR=0.182), and Self-Employment (6) (OR= 8.275) as the primary occupation. Results revealed that males (OR=2.849) are more likely to accept agro-tourism as an income generation activity. People who are currently engaged in tourism activities are more likely to accept the agro-tourism activities (Table 6). 'Kelulut' bee agro-tourism farm, preference to the types of agro-tourism products, encouragement to get involved in 'Kelulut' bee farming, economics impacts, educational level, and gender affected to local community's overall perception of 'Kelulut' honey as the agro-tourism product (Kunasekaran et al., 2018).

**Table 6: Factors contributing to community inclination to participate in agro-tourism**

| Type | Odds Ratio | Estimate Value | Pr Value | 95% Conf. |
|---|---|---|---|---|
| Intercept | | 3.0693 | **0.0015*** | |
| Gender | 2.849 | 0.5236 | **0.0106*** | 1.276-6.362 |
| **Age** | 0.977 | -0.0235 | 0.1758 | 0.944-1.011 |
| Primary occupation | | | **0.0015*** | |
| None | 3.284 | 0.9693 | **0.0415*** | 0.184-58.759 |
| Student | 0.176 | -1.9579 | **0.0083*** | 0.007-4.575 |
| **Farming** | 0.999 | -0.2205 | 0.6377 | 0.060-16.767 |
| **Government sector** | 0.835 | -0.4001 | 0.4489 | 0.046-15.034 |
| Private sector | 0.182 | -1.9210 | **0.0050*** | 0.008-4.076 |
| Self-Employment | 8.275 | 1.8934 | **0.0582*** | 0.245-279.398 |
| **Business** | 7.975 | 1.8566 | 0.0745 | 0.231-275.396 |
| **Harvesting resources from the forest** | 1.698 | 0.2648 | 0.2338 | 0.710-4.062 |
| Engage in tourism activity | 6.333 | 0.9229 | **0.0103*** | 1.545-25.962 |
| Awareness about the agro-tourism activities | 8.106 | 1.0463 | **<.0001*** | 3.486-18.847 |

***Source:*** **Field survey data, 2019** ***Significant at 5% level**

## 4. Conclusions

There are many potentials to attract visitors to the *Palugaswewa* area. The traditional value and prevailing beauty of the *Palugaswewa* tank cascade systems, potentials for wild animal tours, nearby *Habarana* and *Ritigala* tourism hotspots, preserved traditional agricultural and medicinal practices by the cascade residents, available ancient ruins in the area, and prevailing infrastructure facilities in the cascade are the top most potentials and possible ventures identified by the study in *Palugaswewa* tank cascade systems.

The majority of the villagers have positive attitudes on introducing agro-tourism for the *Palugaswewa* tank cascade systems. Gender, educational level of villagers, primary occupation, engaging in tourism activity, awareness about the agro-tourism in *Palugaswewa* are significantly contributing to community inclination to participate in agro-tourism. The majority of females do not accept agro-tourism to *Palugaswewa* due to social problems like drug addiction and crimes. People who have completed secondary education, villagers who involve in tourism at present do agree to introduce agro-tourism to *Palugaswewa* cascade systems mainly since they believe that the concept can develop their village. The majority of students do not accept the concept mainly due to a lack of awareness. Also, social, social welfare, environmental, and land associated factors are significantly affecting community perception of Agro-tourism in this area.

A baseline survey should be done before the implementation of the agro-tourism development plan to recognize the present socio-economic and cultural status of the *Palugaswewa* tank cascade system. Impact assessment should be done to access the impacts of the implemented agro-tourism plan. It is better to introduce sustainable agro-tourism plans to other areas in Sri Lanka as in the *Palugaswewa* tank Cascade system to uplift the livelihood of people, protect the environment and traditional culture. Further, it is proposed to conduct awareness programs to the aware community about agro-tourism.

## 5. Acknowledgment

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# Cost of household air pollution in Bangladesh

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**Abstract**

In Bangladesh, the majority of households use conventional fuels like fuelwoods, biomass, animal waste etc., for cooking and heating purposes that emit various toxic substance like carbon di-oxide, carbon monoxide and other high level of harmful particulate matters (PMs). These (PMs) have created different types of respiratory diseases in the family member of the household. Women and children are becoming more vulnerable with the emission of these PMs, as they are spending more time in the indoor environment. The purpose of this study is to assess the health cost due to household air pollution (HAP) for the use of traditional cooking fuel using cost of illness method. A total of 160 urban and rural household were surveyed in Khulna districts of Bangladesh to estimate the associated health cost due to HAP. The study found that due to poor ventilation system and congested kitchen area, the majority of the households are exposed to smoke duringthe time of cooking. The most suffered diseases are headaches, eye irritation, cough, asthma, and skin diseasesconnected with the emission of smoke from biomass. The treatment cost increases by BDT 205.729 for urban households than the rural households who use traditional stove. It is also revealed that 32 percent of the HH use improved stove in removing smoke. Therefore, if households' members in the urban areas fall sick, the treatment cost is higher by BDT 445.056 compared to the rural area. To recommend, the attempt of the NGOs can play a participatory role to provide HH financial help to undertake cleaner fuel and abate HAP.

**Keywords:** *Treatment cost, household air pollution (HAP), biomassfuel, cost of illness, Bangladesh*

## 1. Introduction

In developing countries, including Bangladesh, Household Air Pollution (HAP) is one of the responsible factors for causing health risk at the household level (Lim et al., 2012). Around 41 percent of global household, are dependent on solid fuel for cooking purpose in 2010 (Bonjour et al., 2013). Solid fuel is the primary cooking fuel in Bangladesh; around 86 – 88 percent of the total population is relied on it (NIPORT et al., 2013).Consequently, the major source of HAP is the use of traditional fuel for cooking and heating purpose. Household is considered as a unit of analysis because the use of every fuel carries a cost to the household. Some have direct costs; others have indirect costs, while others have both in different proportions. This study focuses on estimating indirect health costs due to HAP. Hence, this paper will destine health hazards affiliated with HAP. The fundamental purpose of this paper is to examine the extent to which domestic cook experience health threats related to the cooking environment.

Traditional and open fire stoves for cooking and heating generate a high level of health-damaging pollutants. HAP is thought to cause about a-third of acute respiratory infection, one of the leading causes of child mortality globally. This makes solid fuels the second most environmental cause of the disease after contaminated waterborne disease(Bruce et al., 2006). Another study indicates that environmental insults can have long-lasting influences on health and productivity (Almond, 2006).The major environmental health problem in Nepal is the burning of solid biomass fuel for cooking. Around 85 percent of Nepalese households are dependent on biomass for cooking purposes. Most household cook in a poorly ventilated kitchen using inefficient stoves, leading to indoor air pollution and, consequently, health problems. This pollution level is 15 times higher than the recommended safe level, leading to higher health expenditures (Thakuri, 2009). People in developing countries use solid fuels because of their availability and affordability (Smith et al., 1994).

In developing countries, households with limited ventilation exposures experienced by household members, mainly women and young children who spend most of their time indoors (Bruce et al., 2006). Air pollution levels significantly affect human health, especially the infant and young children (Duflo et al., 2008). There is evidence that is a relationship between HAP and health problems such as acute respiratory infections and chronic obstructive pulmonary disease (COPD) and women's lung cancer(Ezzati and Kammen, 2002). Approximately, 1.5 percent of death is responsible for HAP. Infants remain at home and breathe indoor smoke, and are exposed to these hazardous pollutants. Consequently, 56 percent of deaths occur in children under five years of age due to Indoor Air Pollution. (Chandramohan et al., 2010).

It is important to look other than the major effects on health in measuring the costs of indoor air pollution. As the individual is in poor health, they may not be able to perform arduous or unrelenting work. This minimizes his labor market opportunities and paid lower wages. The household cannot always afford to pay for goods that could improve his health, which are- better fuel, more nutritious foods, doctor's visit, and, therefore, improve his working capability. Thus it becomes a vicious circle of poverty (Dasgupta et al., 2004a).

Another study uses morbidity relationship for the diseases responsible for HAP in terms of sick days. The health burden from 1.6-2.0 billion days of work days lost in India (Smith, 2000). Interventions in many forms can reduce indoor air pollution. For reducing exposure to indoor air pollution, a wide range of interventions are required. These can be categorized into three headings: sources (type of stove, fuel); living environment (housing, ventilation); user behavior (protection of child, fuel drying)(Schrinding et al., 2000). Interventions fall into two categories: access to improved ventilation and access to cleaner fuel (Smith, 1987).

The potential determinants of exposure to indoor pollution are: time spent on cooking, fuel type, structure of houses, location of cooking, and household ventilation. The indoor air quality vary depending on the type of cooking style, type of fuel, hours of burning fire, ventilation and location of kitchen and stove (Dasgupta et al., 2004). In 2000, more than 1.6 million deaths and over 38.5 million Disability-Adjusted LifeYears (DALYs) were attributable to indoor smoke from solid fuels. Cooking with solid fuels is responsible for a significant proportion, about 3 percent global burden of disease (Smith et al., 2004).A major sources of HAP and related illness is the use of traditional biomass fuels for cooking which is used by many rural households (Plant, 2008).

A study from Bangladesh links the level of (Indoor Air Pollution) IAP with wall and roof, location of the kitchen and its openness to other rooms in the house. The construction wall and roofs have a significant effect on IAP concentration. The fuel choice is considered less important than ventilation factors explaining variation in IAP among poor households. Moreover, lack of awareness among rural households is the prime factor in preventing the severity of HAP (Dasgupta et al., 2004).

Regarding the other's relevant studies, the main focus of this study is to estimate the health cost of household air pollution in both rural and urban areas of Bangladesh. Tobit model is used to estimate the treatment cost due to HAP in different perspectives. The cost of illness method is applied to estimate the different cost scenarios in urban and rural areas regarding five types of HAP-related diseases. In the study area, urban dwellers incur more health costs than rural people. Variuos factors are responsible behind the higher treatment cost in urban areas, for example, congested kitchen space, poor ventilation system, higher living cost, etc.

## 2. Methods of Data Collection

To attain the objective of this study, the author selected the Khulna district of Bangladesh as the study area. Khulna district consists of 9 Upazila (sub-district) and one City Corporation (BBS, 2011). On the basis of the administrative boundaries, Khulna City is considered as an urban sample area and Batiaghata Upazila is randomly considered as a rural sample area. Questionnaire survey method was implemented for the purpose of data collection amd majority of the questions are in a structured form.

Households, where fuelwood is partially or fully used for cooking and heating purpose, are considered as sample data. A total of 160 households have been surveyed for this study using the multistage sampling technique.

Khulna City Corporation (KCC) consist of 31 wards, including 184 Mahallas (BBS, 2011). Among 31 wards of KCC, three wards have been selected randomly.

Out of 9 Upazilazs of Khulna District, Batiaghata Upazilahas been selected for the convinence; it consists of 7 unions and 172 villages (BBS. 2011). The two unions have been randomly chosen among the 7 unions of this Upazila. Under each union from the village population list, two villages have been chosen randomly for the study

Thus 80 households from urban area and 80 from rural areas (a total of 160 households) have been selected for the study. As the main purpose of this study is to estimate the health cost of household air pollution (HAP) in the household (HH) sector, it is convenient to trace out the health cost of HAP related diseases like eye irritation, headaches, coughing, pulmonary disease, etc. at HH sectors.

### Analytical Framework

At households sector, use of biomass fuel like fuelwood, plant and animal residues for cooking and heating purpose that deteriorates the HH air quality compared to the benchmark of international ambient air quality (Larsen, 2016). As women and children are situated in the house most of the time, they are the main exposure to HAP. There are some specific effects of HAP like increase the health cost of affected people, reduces the workdays, etc. In this paper, the cost of illness (COI) method is applied to estimate the health cost of HAP. COI is the most commonly and popularly used method which is defined as the cost of medical care resulting from sickness plus lost productivity due to sickness (Freeman, 1993).

**Estimation of Treatment Cost**

An important characteristic of the survey data on mitigating activities is that it usually has several observations where the medical expenditure is zero. This feature of the data destroys the linearity assumption; hence the application of the least-squares method is inappropriate. Therefore, to estimate the treatment cost of illness in both urban and rural area, the author uses a Tobit model (Atreya, 2007). In the Tobit model author has considered the upper and lower limit of the data of the related variables.

$$M_{ti} = \sum_{i=1}^{n} \gamma X_i + e_i \text{ .................... (1)}$$

Where, *Mti* is the Treatment costof illness

*γ* is the vector of the regression coefficient for the individual's treatment expenditure

*Xi* is the vector of the exogenous independent variable. The variables used in the treatment cost analysis are explained in Table 1:

**Table 1: Variables for Treatment Cost Analysis**

| Explanatory Variable | Unit of Measurement | Exp. Sign | Reference |
|---|---|---|---|
| Age | Years | + | Author's Compilation |
| Income | BDT/Year | + | (Thakuri, 2009) |
| Smoke | 1= Yes, 0=Otherwise | + | (Thakuri, 2009) |
| Chronic illness | 1= Yes, 0= Otherwise | ? | (Thakuri, 2009) |
| Distance to hospital | Km | + | (Thakuri, 2009) |
| Size of family | No. | ? | Author's Compilation |
| Frequency of illness | Frequency/Year | + | (Thakuri, 2009) |
| Fuel consumption | Kg/month | | Author's Compilation |
| Hours of cooking | Hours/Day | + | (Thakuri, 2009) |

***N.B.:*** Dependent Variable: Treatment Cost (BDT/person).
Source: Author's Compilation, 2021

N.B.: Dependent Variable: Treatment Cost (BDT/person).

Source: Author's Compilation, 2021

Cost of Illness Calculation

Here, $L = \sum_{i=1}^{n} (A_{ij}) D$ ................. (2)

Where, $A_{ij}$ is the proportion of exposed persons experiencing i days of the lost normal activity of each illness (j), D is the income per workday (in BDT)

We know,

$$C = L + M \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Where, L= Lost income per illness (BDT), M= Medical cost (BDT), C= Total cost per illness (BDT)

## 3. Result and Discussion

Households usually undertake treatment when exposed to pollution. They visit doctors or take various medicines due to the disease related to indoor air pollution. In the sample, the cost of treatment is zero for several households. In that case, loss of income is considered as the opportunity of of illneness. So, for the truncated nature of the dependent variable, the author uses the Tobit regression for estimation of the treatment cost. A Tobit regression analysis is used here to determine the factors that affect the treatment cost, taking treatment cost as the dependent variable. Factors that influence the cost of treatment are explained in Table 2.

The model depicts that the treatment cost increases by BDT 205.729 for urban households than the rural households that uses traditional stove, which is statistically significant at 1 percent level.

**Table 2: Estimation of Treatment Cost**

**Table 2: Estimation of Treatment Cost**

| Tobit Model | | | | |
|---|---|---|---|---|
| | | **Model 1[a]** | **Model 2[b]** | **Model 3[c]** |
| **A** | **B** | **C** | **D** | **E** |
| **Explanatory Variable** | **Unit of Measurement** | **Coefficient** | **Coefficient** | **Coefficient** |
| Age | Years | 2.656 | 2.409 | 0.686 |
| Income | BDT/Month | -0.002 | - | 0.000 |
| Smoke | Yes = 1, No = 0 | 403.960** | 336.403*** | -0.362 |
| Ventilation | Yes = 1, No = 0 | -48.752 | 16.381 | -38.231 |
| Fire wood Consumption | Kg/Month | 0.0283 | 0.043 | -38.231 |
| Frequency of Illness | Times | 164.056*** | 29.627 | 48.967 |
| Total hours of cooking | Hours | 45.843 | -8.912 | 10.667 |
| Size of Family | Member | -78.767 | 36.676 | -4.891 |
| Traditional Chula | Yes = 1, No = 0 | 68.284 | 35.799 | 205.729*** |
| Illness | Yes = 1, No = 0 | - | - | 445.056*** |
| Location | Urban =1, Rural=0 | - | - | 139.493 |
| Constant | | -602.143 | -208.836 | -549.068 |
| Sigma | | 456.224 | 217.348 | 358.436 |
| LR $chi^2$ (10) | | 23.790 | 29.770 | 90.00 |
| Prob > $chi^2$ | | 0.0082 | 0.0009 | 0.000 |
| Log likelihood | | -519.749 | -448.520 | -926.349 |
| Pseudo $R^2$ | | 0.0224 | 0.032 | 0.046 |
| Number of observation | | 80 | 80 | 160 |

***N.B.:*** *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Dependent Variable: Treatment Cost (BDT/Person). [a] Model 1= Regression for Urban Area, [b] Model 2= Regression for Rural Area, [c] Model 3= Combined Regression for both urban and rural area.

Source: Author's Compilation based on Field Survey, 2021

Therefore, if households' members in the urban area fall sick, the treatment cost is higher by BDT 445.056 compared to the rural area, which is statistically significant at 1 percent level. Frequency of illness is higher in rural areas compared to urban areas, which is 1 percent significant. The variables like smoke is one of the significant factor to increase the treatment cost in both urban and rural areas.Use of traditional cooking system also positively influence the dependent variable at significant level.

**Calculation of Total Cost of Illness**

To estimate the health cost of pollution exposure, the estimation for each type of illness occurrence is multiplied by their respective estimates of the episodes of illness for the exposed household. The loss days for the households are 1, 2 and 3. Loss days of activity are found from each type of illness in the field survey. The loss of income is estimated from the proportion of loss days multiplied by the income per workday. Then, the medical visit per illness is found from the proportion of people who are sick and their visit for medical treatment. Now the medical cost per illness is estimated by multiplying the proportion of medical visit/illness to medical cost per visit. Finally, the total cost of illness is found from the summation of effective daily income and medical cost/disease. Then total cost of illness is estimated in two different areas; urban and rural which would be helpful for area wise effecting decision making.

**Cost of Illness for Rural Area**

By following the cost of illness method by (Dwight et al., 2004) , the total cost of illness for the surveyed villages is BDT 24,811.30.Table 3 calculates the total loss income in a rural area. The proportion value of illness is multiplied by the effective daily income of the individual. The proportion of medical visit is similarly multiplied by the medical cost per visit. Then, the total cost of illness is found by summing the value of total loss income and medical cost /visit, which is BDT 24,811.30.

**Table 3: Cost of Illness for Rural Area**

| Explanatory Variable | Unit of Measurement | Exp. Sign | Reference |
|---|---|---|---|
| Age | Years | + | Author's Compilation |
| Income | BDT/Year | + | (Thakuri, 2009) |
| Smoke | 1= Yes, 0=Otherwise | + | (Thakuri, 2009) |
| Chronic illness | 1= Yes, 0= Otherwise | ? | (Thakuri, 2009) |
| Distance to hospital | Km | + | (Thakuri, 2009) |
| Size of family | No. | ? | Author's Compilation |
| Frequency of illness | Frequency/Year | + | (Thakuri, 2009) |
| Fuel consumption | Kg/month | | Author's Compilation |
| Hours of cooking | Hours/Day | + | (Thakuri, 2009) |

***N.B.:*** Dependent Variable: Treatment Cost (BDT/person).
Source: Author's Compilation, 2021

**Table 2: Estimation of Treatment Cost**

| | | Tobit Model | | |
|---|---|---|---|---|
| | | **Model 1[a]** | **Model 2[b]** | **Model 3[c]** |
| **A** | **B** | **C** | **D** | **E** |
| **Explanatory Variable** | **Unit of Measurement** | **Coefficient** | **Coefficient** | **Coefficient** |
| Age | Years | 2.656 | 2.409 | 0.686 |
| Income | BDT/Month | -0.002 | - | 0.000 |
| Smoke | Yes = 1, No = 0 | 403.960** | 336.403*** | -0.362 |
| Ventilation | Yes = 1, No = 0 | -48.752 | 16.381 | -38.231 |
| Fire wood Consumption | Kg/Month | 0.0283 | 0.043 | -38.231 |
| Frequency of Illness | Times | 164.056*** | 29.627 | 48.967 |
| Total hours of cooking | Hours | 45.843 | -8.912 | 10.667 |
| Size of Family | Member | -78.767 | 36.676 | -4.891 |
| Traditional Chula | Yes = 1, No = 0 | 68.284 | 35.799 | 205.729*** |
| Illness | Yes = 1, No = 0 | - | - | 445.056*** |
| Location | Urban =1, Rural=0 | - | - | 139.493 |
| Constant | | -602.143 | -208.836 | -549.068 |
| Sigma | | 456.224 | 217.348 | 358.436 |
| LR $chi^2$ (10) | | 23.790 | 29.770 | 90.00 |
| Prob > $chi^2$ | | 0.0082 | 0.0009 | 0.000 |
| Log likelihood | | -519.749 | -448.520 | -926.349 |
| Pseudo $R^2$ | | 0.0224 | 0.032 | 0.046 |
| Number of observation | | 80 | 80 | 160 |

***N.B.:*** *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Dependent Variable: Treatment Cost (BDT/Person). [a] Model 1= Regression for Urban Area, [b] Model 2= Regression for Rural Area, [c] Model 3= Combined Regression for both urban and rural area.
Source: Author's Compilation based on Field Survey, 2021

## Cost of Illness for Urban Area

The cost per illness is calculated using the cost of illness model. Table 4 calculates the total loss income in a particular area. The proportion value of illness is multiplied by the effective daily income of the individual. The proportion of medical visit is similarly multiplied by the medical cost per visit. Then, the total cost of illness is found by summing the value of total loss income and medical cost per visit, which is BDT 32,692.39. Here it has been seen that cost of illness is higher in urban area compared to rural area (table:3).

**Table 4: Cost of Illness for Urban Area**

**Tobit Model**

| | | **Model 1[a]** | **Model 2[b]** | **Model 3[c]** |
|---|---|---|---|---|
| **A** | **B** | **C** | **D** | **E** |
| **Explanatory Variable** | **Unit of Measurement** | **Coefficient** | **Coefficient** | **Coefficient** |
| Age | Years | 2.656 | 2.409 | 0.686 |
| Income | BDT/Month | -0.002 | - | 0.000 |
| Smoke | Yes = 1, No = 0 | 403.960** | 336.403*** | -0.362 |
| Ventilation | Yes = 1, No = 0 | -48.752 | 16.381 | -38.231 |
| Fire wood Consumption | Kg/Month | 0.0283 | 0.043 | -38.231 |
| Frequency of Illness | Times | 164.056*** | 29.627 | 48.967 |
| Total hours of cooking | Hours | 45.843 | -8.912 | 10.667 |
| Size of Family | Member | -78.767 | 36.676 | -4.891 |
| Traditional Chula | Yes = 1, No = 0 | 68.284 | 35.799 | 205.729*** |
| Illness | Yes = 1, No = 0 | - | - | 445.056*** |
| Location | Urban =1, Rural=0 | - | - | 139.493 |
| Constant | | -602.143 | -208.836 | -549.068 |
| Sigma | | 456.224 | 217.348 | 358.436 |
| LR $chi^2$ (10) | | 23.790 | 29.770 | 90.00 |
| Prob > $chi^2$ | | 0.0082 | 0.0009 | 0.000 |
| Log likelihood | | -519.749 | -448.520 | -926.349 |
| Pseudo $R^2$ | | 0.0224 | 0.032 | 0.046 |
| Number of observation | | 80 | 80 | 160 |

***N.B.:**** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Dependent Variable: Treatment Cost (BDT/Person). [a] Model 1= Regression for Urban Area, [b] Model 2= Regression for Rural Area, [c] Model 3= Combined Regression for both urban and rural area.

Source: Author's Compilation based on Field Survey, 2021

## 4. Conclusion

The households cooking behaviour varies from households to households. Some spend more hours in the kitchen and others less depending on the activities. According to the survey findings, about forty-one percent of the households with traditional stove spend more hours in the kitchen than other types of the stove like gas, kerosene and electric. The mean hours spent is 4.5 hours per day.

This paper finds that the major health problem faced by households in the study area is eye irritation, headache, cough, asthma, skin disease. This study finds that average sick days as a result of indoor air pollution are 0.711 days /episode.

This study focuses on the generation of HAP through household's cooking behaviour and also the plausible health symptoms of HAP. The sets of essential factors responsible for the health cost of IAP are presented in this paper. The analysis shows that smoke and extensive use of traditional stove are responsible factors for the health damages of households. Moreover, the surveyed area is highly dependent on solid biomass fuel as it is readily available and cheap. For the higher cost of adopting cleaner energy, the households stick to the traditional way of cooking, although this type of fuel gives off corrosive fumes which is harmful to health. This fuel is not only creating health cost but also creating environmental cost by deforestation. As with the other basic needs as food, clothing, shelter and health the supply of household energy is also crucial. Therefore, it is a crying need to ensure a sustainable and alternative supply of energy for the household sector through planned policy. Different interventions from the part of government can help to reduce the HAP. In this regard, the NGOs and INGOs can play a participatory role to create awareness among the households about the negative externalities of air pollution at household level. By providing financial support to adopt user friendly cooking system to the households, cost of illnesd due to HAP can be reduced.

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# Adapting Sustainable Development Goals (SDGs) in sustainability reporting (SR) by listed firms in Sri Lanka

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**Abstract**

Sustainable Development Goals are a set of guidelines established by the United Nations in 2015 for the world to be aligned towards sustainable future. Business firms embrace these concepts of SDGs in to their Sustainability Reporting (SR) cycle to show that they are responsible towards the society, environment and economy they operate in. The level of diffusion of the SDGs in to the corporate SR cycle of firms in a developing country such as Sri Lanka is unidentified up to date. The objective of this study was to examine the level of incorporating SDGs in SR practices of firms in Sri Lanka. The influence of firm characteristics on this corporate decision was also investigated through the study. Panel data regression model was applied for a data set compiled through content analysis of annual reports from 2015-2019 of 25 companies with the highest market capitalization, listed in the Colombo Stock Exchange (CSE). Results reveal that there is a growth in the number of SDGs incorporated reports and firm revenue is a significant factor that positively affects the decision of incorporating SDGs in corporate reporting of Sri Lankan firms.

**Keywords:** *Corporate Sustainability Reporting, Content Analysis, Firm characteristics, Panel data Regression, Sustainable Development Goals*

## 1. Introduction

Sustainable Development Goals (SDGs) were formulated by the United Nation member states in 2015 as an urgent call for action for all countries to reduce poverty, protect the planet and to achieve peace and prosperity for all nations by 2030. According to the report by Business and Sustainable development commission of United Nations in 2017, it was discovered that achieving the Global Goals opens up US$12 trillion of market opportunities in the four economic sectors; namely in the areas of food and agriculture, energy and materials, health and well-being and cities (Business and Sustainable Development Commission, 2017). It also specifies that businesses and the global SDGs have interdependency with each other, where SDGs provide a compelling growth strategy for the individual businesses and business community seize the market opportunities which the SDGs offer and advance progress towards the range of goals.

After the introduction of the SDGs in September 2015, only few of the companies have accepted and incorporated the SDGs in to their strategic management process. The most widely acknowledged reason for the decision to neglect SDGs in setting corporate objectives was that, as SDGs were formulated as an intergovernmental initiative, the goals appeared to lie beyond the scope of interest of the companies. SDGs may appear to be incompatible with the normal decision-making process of the firms. However, understanding the meaning of the goals with related to the businesses are important. Integrating the idea of these SDGs into the corporate strategic management process may offer the overall businesses a competitive advantage over the others that do not.

Although the companies may believe involving in Corporate Social Responsibility (CSR) activities is a method of showing their devotion towards sustainable development, companies typically practice these norms for their profit motives. Nevertheless, the incorporation of SDGs into the corporate vision and strategies would provide competitive advantage to the companies and gain access to more market opportunities particularly in the international market.

Incorporating SDGs in to corporate sustainability reporting may offer the companies with numerous benefits. For example, the firms may enhance their corporate reputation in the global market with reporting their sustainable performance. This means that through the enhanced firm reputation, the companies may attract and retain their employees, customers, investors and other stakeholders associated with the company and safeguarding their authorization to operate. Moreover, by incorporating the SDGs in the corporate strategy and reporting cycle of the firms, new opportunities will open up and immense efficiency gains could be reached while driving innovation (Business and Sustainable Development Commission, 2017).

Sri Lanka which is a South Asian, United Nations member state, actively participate in the road towards achieving the global SDGs. Sri Lanka was ranked in the 94$^{th}$ position out of the 193 member states in achieving the SDGs and was given a score of 66.8%, while countries like Sweden, Denmark and Finland were ranked the top achievers of SDGs with the highest SDG score of 84.72% in 2020 (Sachs, 2020). This shows that Sri Lanka has an opportunity and a long journey ahead towards achievement of the SDGs and gain a significant position among the world leaders. Existence as a lower middle-income developing country, offers Sri Lanka numerous challenges in the business world, which also turns out to be favorable market opportunities. In a background where the Sri Lankan government is eagerly anticipating to achieve the SDGs by 2030, firms in Sri Lanka also have an open opportunity to exhibit to the world that their business is responsible and committed to achieve a sustainable future for all. Sustainability reporting could be identified as a method by which firms could reveal their economic, social and environmentally sustainable performance to their stakeholders (Dilling, 2010). Sri Lanka being a developing country may take some time in adapting and familiarizing with these globally accepted SDGs. Therefore, it is substantial to explore how firms incorporate the concept of SDGs in to their corporate strategy and to the reporting practices.

The main objective of this research was to examine the extent of using SDGs in sustainability reporting (SR) practices of firms in Sri Lanka. Although successful firms tend to report on their sustainability performance through their sustainability reports, the study intends to examine to what extent these top Sri Lankan companies have used the SDGs and integrated them to their reporting practices and the factors that have influenced the SDGs incorporation. This will indirectly examine the level of SDGs awareness among business community in Sri Lanka. A sample of 25 companies listed in the Colombo Stock Exchange with the highest market capitalization were selected, and secondary data were extracted from annual reports for a 5-year time period from 2015- 2019. After conducting content analysis, a panel data regression analysis was employed to achieve the research objectives. It was concluded that there is a positive trend and a growth in the number of companies which reports SDGs in their corporate sustainability reports of firms in Sri Lanka and firm revenue was identified to be determinant of incorporating SDGs in corporate sustainability reporting.

## 2. Literature Review

*The Sustainable Development Goals and Businesses*

Sustainable Development Goals were introduced by the end of the year 2015, the birth of the SDGs dates back decades before and consist of the hard work by countries and United Nations (UN). These 17 Goals were an extension to the 8 Millennium Development Goals (MDGs) and was designed and set forth in 2015 to reduce poverty, protect the planet and achieve peace and prosperity by the end of next 15 years (Department of Economic and Social Affairs, 2020). These SDGs were held to be impracticable by the firms as it was introduced as an intergovernmental initiative. However, the nations should have an improved economic background to fully achieve these targets by 2030. The responsibility to build a sound economy rests upon the country's business organizations partially and guide the nation towards a sustainable future.

Incorporating SDGs in the corporate strategy will benefit the world to achieve a sustainable future and also benefit the company in long term. By means of incorporating SDGs into the businesses, it offers a compelling growth strategy for their businesses and improve the firm performance over time. Similarly, the global goals are also benefited through the incorporation of the SDGs to businesses as the businesses would adopt the market opportunities the SDGs offer and progress faster towards achievement of the whole range of goals within the years (Business and Sustainable Development Commission, 2017) The Goal 12 of the 17 SDGs concerned with the topic "Ensure Sustainable consumption and production patterns" is explicitly formulated to ensure a sustainable economy through efficient consumption and production patterns (United Nations, 2020). Target 6 of this 12th Goal addresses corporate sustainability reporting where the companies are encouraged, specifically the large transnational companies to adapt sustainable practices and to integrate them in to their corporate sustainability reporting cycle. The report by United Nations states that since 2017, the overall quality of the sustainability reports around the world have improved. However, it was reported that large disparity was observed with regard to the countries and regions with regards to the sustainability reports (United Nations, 2020).

*SDGs and Corporate Sustainability Reporting*

Extent research has been conducted on the theme of corporate sustainability reporting by different authors since the introduction of the concepts of "Sustainable Development" in 1987 (Bhatia & Tuli, 2018; Hahn & Kuhnen, 2013). Carp, Păvăloaia, Afrăsinei, & Georgescu (2019) defines Sustainability Reporting as a method of reporting information related to sustainability development of major companies as a means of exhibiting their concern for increasing the transparency of the activities conducted for promoting corporate sustainability. Unlike Financial Reporting, Sustainability reporting is not regulated by law and the individual companies who publish these reports have freedom to decide which information to include and not in their sustainability reports (Sandberg & Holmlund, 2015).Hence, the business leaders or the top management of firms have the authority to decide whether they would disclose their sustainability performance to their stakeholders or not. The sustainability reporting is more focussed on how the firm progress towards social and environmental sustainability, since the economic performance is a mandatory requirement in publishing the corporate disclosures. Global SDGs are harmoniously, focussed on these same social and environmental aspects together with last goals (Goal 12, 16 and 17) focussing on monitoring the SDGS, values and governance.

Some researchers have used the Global Reporting Initiative (GRI) guidelines and the UN Global Compact to design the disclosure topics for conducting content analysis, to measure SDGs incorporated sustainability performance or sustainability reporting. For example, Tsalis, et al. (2020) have developed a methodological framework for evaluating the level of corporate sustaianbility reporting practises with UN SDGs with regards to Greek firms. This framework was built as a sustaianbility disclosure matrix and a measurement system and have used the GRI guidelines for creating the disclosure topics used for the analysis.

A similar study was conducted to examine the extent of diffusion of SDGs into various instruments of disclosures in the listed companies in the Italian National Stock Exchange (Izzo, et al., 2020). Content analysis was used to identify word phrases related to SDGs in the annual reports, sustaianbility reports,integrated reports etc.It was determined in the study that SDGs related disclosures mainly ocuurs through the sustaianbility reports and non financial statements where a separate section is allocated for the SDGs achievement of that particular company. It was concluded through the study that awarness related to SDGs whithin the business community is higher and more capitalized firms have incorporated SDGs in their disclosures.

The research related to sustianbility reporting in Sri Lanka is very limited. Some researchers have focussed their attention on exploring the determinng factors of sustaianbility reporting of firms in Sri Lanka (Dissanayake, et al., 2016 ; Dissanayake, et al., 2019; Mudiyanselage, 2018). As per our understanding, although some studies have been conducted in other country settings on determining the extent of incorporating SDGs in to firms' reporting cycle, no prior study has been conducted in Sri Lanka to identify the extent of which Sri Lankan companies have incorporated SDGs into their sustainability reporting practices.

In our study, it was intended to address the research question of the extent to which Sri Lankan companies have incorporated the concept of SDGs in their corporate sustaianbility reporting cycle. Further, the study examines how the firm specific characteristics such as firm size, leverage, profitability and age affects on SDGs incorporated sustaianbility reporting practices. Since firm specific characteristics mentioned above were discovered to be significant determinents in the firm decision related to sustaianbility reporting practises (Hahn & Kuhnen, 2013), the same charcteristics were used as variables to identify the incorporaton of SDGs in sustainability reporting.

## 2. Methodology

*Sample Selection*

The study employed the top 25 companies listed in the Colombo Stock Exchange (CSE) with the highest market capitalization as at June 15th 2020 for conducting the research following the previous research studies. (Izzo, et al., 2020; Dissanayake, et al., 2016),

*Research Methodology*

As illustrated in previous sections, the purpose of our study was to examine the extent of incorporating the global SDGs in to the reporting cycle business companies in Sri Lanka and their determining firm characteristics. In other words, the study aims to explore the preference of top-rated firms towards incorporating the concepts of SDGs in their corporate reporting cycle and analyze whether the firm specific characteristics would affect the publishing of the SDGs in their reports. For this purpose, the study will use a panel data regression analysis based on content analysis for the annual reports from 2015 to 2019.

Content analysis was conducted with the annual reports from 2015-2019 time periods, for the top 25 companies with highest market capitalization using the NVivo software. Data were collected in two folds. First, a binary variable (SDG Usage) was created to represent whether the firm has incorporated the concepts of SDGs in their annual report in a particular year or not. The binary variable was given a value of 1, if the firms' annual report contains any information about the global SDGs in their reported content and a value of 0 is given otherwise.

Second, the word frequency of the keyword of "Sustainable Development Goals" or "SDGs" or "Sustainability Development Goals" were taken in to account as the dependent variable for the analysis. The total word frequency of using the word related to Sustainable Development Goals were computed by adding the individual keyword frequencies and for each annual report. It was assumed that the extent of incorporating SDGs in to sustainability reporting is denoted by the word count on the "SDG" in the report examined for a firm in the particular year.

The firm characteristics that may have an influence on the firm decision on SDGs reporting were selected as the independent variables; namely the natural logarithm of the total assets, the debt ratio, the Earnings Per Share (EPS) value, revenue and number of years from year of establishment of the firm representing the firm size, financial leverage, Profitability and firm age respectively. Many researchers have used the natural logarithm of total assets as a proxy to indicate the size of the firm (Buallay & Al-Ajmi, 2019; Braam, et al., 2016; Dissanayake, et al., 2019; Karaman, et al., 2018; Arayssi, et al., 2016; Meng, et al., 2014). The results of most of these literatures have concluded that firm size has a significant and positive relationship with sustainability reporting practices of firms. Debt ratio (calculated by dividing total liabilities by total assets) was engaged as a proxy signifying the financial leverage of a firm (Onofrei, et al., 2015; John, 1993). Earnings Per Share(EPS) or the portion of company's proft in each outstanding share, calculated as company's profit divided by the outstanding shares of its common stock (Adil, et al., 2011) and firm revenue was recorded as a proxies denoting the profitability of the company (Dissanayake, et al., 2016). Firm age was considered for the analysis and the number of years since establishment till the reporting year was used as a proxy for the firm age (Buallay & Al-Ajmi, 2019; Dissanayake, et al., 2016; Melloni, et al., 2017).

Panel data regression analysis was used for analysing the firm level panel data and the latest version of the STATA statistical software (STATA16) was used for the analysis. The random effect regression model was employed as the best fit model to study the determinents of using SDGs for corporste sustainability reporting. The Hausman test was employed for both Fixed effect model and random effects model, and the results(P=0.38) concluded that the best fitted model was the random effect model for the analysis.Unlike in the fixed effects model , the difference across entities are presumed to be uncorrelated with the independent variables in the model (Wooldridge, 2010).The model used to detemine the impact of firm characteristics on SDGs reporting is as follows;

$$SDG\ reporting_{it} = \beta_1\ FSIZE_{t-1} + \beta_2 LEV_{t-1} + \beta_3 PROFIT_{t-1} + \beta_4 AGE_{t-1} + v_{it}$$

Where,

SDG reporting - the total word count on using SDGs in sustainability reporting of firm I in the year t

$FSIZE_{t-1}$ – size of the firm I in the year t-1

$LEV_{t-1}$ – Firm leverage of the firm I in the year t-1

$PROFIT_{t-1}$ – Firm profitability of the firm I in the year t-1

$AGE_{t-1}$ – Firm age of the firm I in the year t-1

$v_{it}$ – Composite error term

## 4. Results

*Nature of SDGs incorporated corporate sustainability reporting.*

The first stage of the analysis in the study comprised a descriptive analysis of how the firms in the sample, have embraced the concepts of SDGs in their sustainability reporting practices using the binary variable of SDGs usage.

From the 25 top market capitalized companies analyzed in the study, highest number of companies were associated with the Food, Beverages and Tobacco category (28%) while the least number of companies associated to the categories of Apparel, Healthcare services and insurance categories (4%). The selected sample also included companies associated with other industrial categories such as Banks (16%), Diversified Financials (16%), Capital goods (12%), Food and staple retailing (8%) and Telecommunication services (8%) as companies with top market capitalization in Sri Lanka.

**Table 1: SDGs usage in the years from 2015- 2019**

| Reporting year | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| SDG Usage=1, if used SDG in Annual report | 2 | 5 | 11 | 12 | 18 |
| SDG Usage=0, if not used SDG in Annual report | 23 | 20 | 14 | 13 | 7 |
| Total companies selected | 25 | 25 | 25 | 25 | 25 |
| Percentage of SDG usage in each year | 8.00% | 20.00% | 44.00% | 48.00% | 72.00% |

*Source:* **Authors' estimation**

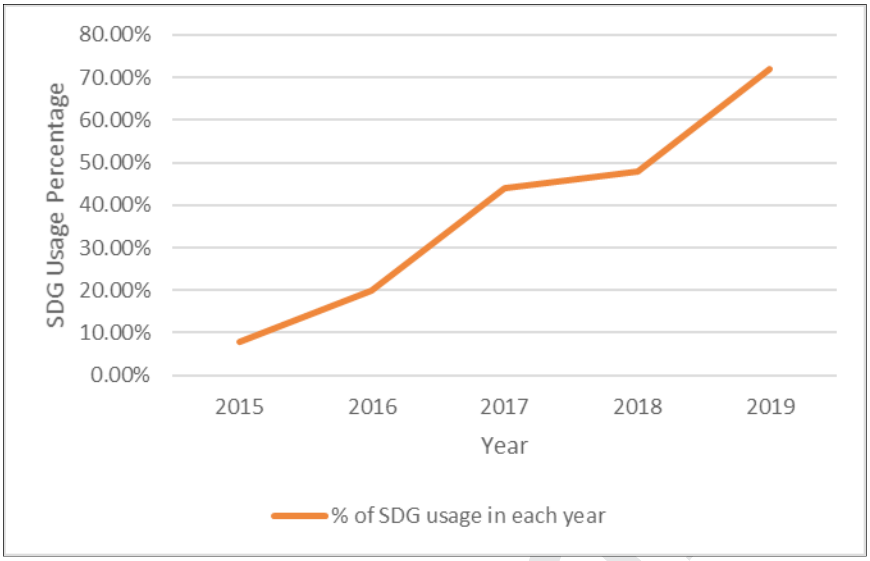


**Figure 1: Graphical representation of SDGs usage in the years from 2015- 2019**
***Source:* Authors' representation**

Figure 1 shows trends of SDGs usage in corporate reporting. It could be observed that, the there is a positive trend from year 2015 till 2019 for the percentage of firms using SDGs in their corporate reporting. Table 1 shows the numeric statistics of the SDG Usage from 2015 to 2019. While 8% of the total sample has incorporated SDGs in sustainability reporting in 2015, by 2019, the percentage has increased to 72% of companies from the total sample. Therefore, it could be observed that, the SDG incorporated reporting has increased significantly during the years from 2015 to 2019.

The second phase of the analysis was the panel data regression analysis which examined the determinants affecting the firm decision of incorporating SDGs to sustainability reporting using the SDGs Score. The descriptive statistics of the data with 125 observations over five year (2015-2019) with 25 Sri Lankan companies is shown in Table 2. It could be observed that the highest score was 29 while the least score was 0. The highest score was obtained by a company associated with the Capital Goods industrial category. A graphical illustration on the SDGs score of the companies during the years 2015-2019 is shown in the figure 2. It could be observed that there is an overall positive trend relating to the SDGs Score in the top market capitalized companies during the years from 2015-2019. The average SDGs score was determined to be 2.208 with a standard deviation of 4.363145.

Table 3 shows a summary of the estimation results of the Random Effect estimation model. All the independent variables used for the study except for the firm revenue in the model appears to be statistically insignificant determinants of the SDGs score since their probabilities are greater than the 5% of 10% level of significance. The revenue is the only determinant that has shown to be positive and statistically significant with 10% level of significance. Therefore, it could be observed that, the revenue of a firm is a determining factor for incorporating SDGs in sustainability reporting in firms of Sri Lanka.

**Table 2: Descriptive statistics of the data**

| | SDG score | Revenue (Rs.) | Debt Ratio | Earnings Per Share (Rs.) | Firm Age (Years) | Ln [Total Assets (Rs.)] |
|---|---|---|---|---|---|---|
| Mean | 2.208 | 4.61e+07 | 0.662865 | 23.78728 | 77.2 | 18.24656 |
| Maximum | 29 | 1.40e+08 | 1.53 | 317.76 | 174 | 21.00083 |
| Minimum | 0 | 1589283 | 0.04 | -233.42 | 14 | 15.94792 |
| Standard Deviation | 4.363145 | 3.31e+07 | 0.2323207 | 52.26423 | 49.06382 | 1.2854 |
| Observations | 125 | 125 | 125 | 125 | 125 | 125 |

***Source:* Authors' estimation**

**Table 3: Panel data regression results**

| Variable | Coefficient | Standard Error | Probability |
|---|---|---|---|
| Revenue | 3.87e-08 | 2.23e-08 | 0.082* |
| Debt Ratio | 0.7022448 | 2.414139 | 0.771 |
| Earnings Per Share | 0.0031779 | 0.0090998 | 0.727 |
| Firm Age | -0.0062179 | 0.0138484 | 0.653 |
| Ln (Total Assets) | 0.3067478 | 0.5739549 | 0.593 |

**Note**: *Significant at 10% level of significance

***Source:* Authors' estimation**

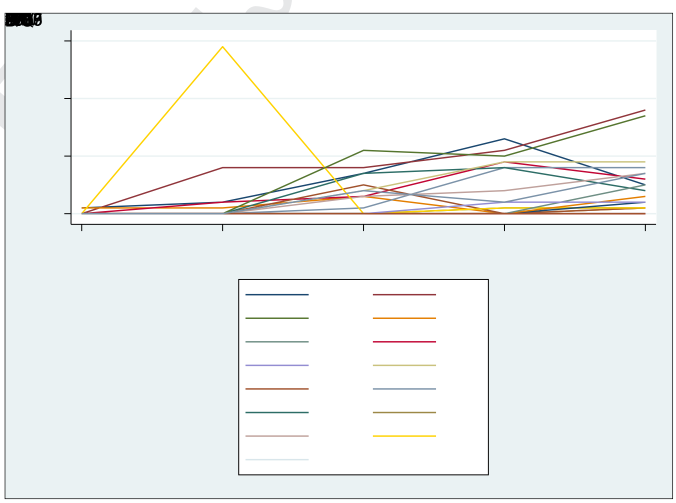

**Figure 2: Distribution of SDG incorporation score for the 25 companies (Top market capitalized companies as at 15.06.2020 are termed from letter A-Y)**
***Source:* Authors' representation**

## 5. Discussion

As illustrated in the Figure 1, the percentage of Sri Lankan companies using the concepts of SDGs in sustainability reporting practices has shown to grow from 8 % in 2015 to 72% in 2019. Although the SDGs were introduced to the world on September 2015, the annual reports or sustainability disclosures of the firms, report on their sustainability performance for the whole year at the end of the year 2015 or at the end of the financial year of the following year. Hence, the year 2015 was taken into account when selecting the sample. As per the descriptive statistics, 2% of the total companies in the sample has reported their sustainability performance with related to SDGs in the year 2015. This demonstrates that the percentage firms embracing the concepts of SDGs as soon as the SDGs were introduced is relatively lower (2%) in Sri Lanka compared with the other countries where a it was reported that a study by GlobeScan found, one third of the companies have used Global goals in setting corporate strategies in 2015 (Business and Sustainable Development Commission, 2017). From this result it could be concluded that, the rate of adoption of SDGs in the initial stages in Sri Lankan corporate sustainability reporting appears to be in a lower level.

Despite having a lower percentage of companies to practice SDGs in Sustainability reporting in 2015, the number of companies incorporating SDGs in sustainability reporting have continued to grow gradually until 2019. These results signify that, there is a growing demand from stakeholders of the companies to incorporate SDGs in their disclosures as a means to attract and retain their business opportunities. This phenomenon could be acknowledged further as the highest percentage of companies reporting SDGs in their annual reports were companies associated with Food, beverages and Tobacco industry and most of them are multinational companies which are having an international business background in conducting operations. When the international relations are high, the firms tend to report their sustainability performance based of globally accepted SDGs and exhibit that their companies are responsible for a sustainable future.

The panel data analysis results have concluded that most of the firm specific characteristics such as Firm size, age, leverage and profitability have insignificant effect on incorporating SDGs in sustainability reporting. Revenue was determined to be the only determinant that would have an impact on the SDGs incorporated sustainability reporting. However, the results showed that firm size which had a significant positive relationship with sustainability reporting in most literatures (Arayssi, et al., 2016 ; Buallay & Al-Ajmi, 2019) have an insignificant relationship with SDGs incorporated sustainability reporting. Similarly, firm age, leverage, a proxy for profitability (EPS) has also shown insignificant relationship with SDGs incorporated sustainability reporting. This signifies that, SDGs incorporated sustainability reporting is less likely to be impacted by firm specific characteristics. As revenue has shown a positive and significant impact towards SDGs incorporated Sustainability reporting, it could be concluded that revenue of a firm could impacts the decision of incorporating SDGs in sustainability reporting practices. This result on revenue is in contrast to the results of analysis done for the determinants of sustainability reporting by Dissanayake et al. (2016). Further, the overall results of the panel data regression analysis could lead to the conclusion that, firm specific characteristics are less likely to affect the decision regarding incorporating SDGs in to corporate sustainability reporting practices of Sri Lankan firms.

## 6. Conclusion

The globally accepted SDGs and business operations have shown to have an interdependency with each other. Our study was conducted to examine to what extent the Sri Lankan firms has embraced the concepts of SDGs in to their reporting cycle from the year 2015 to 2019, and to determine whether firm factors affecting SDGs incorporating decision. A content analysis followed by a panel data regression analysis was conducted for a sample of 25 top market capitalized companies for a period of 5 years using their annual reports data.

The results through the analysis concluded that, there is a positive trend in incorporating SDGs in to the corporate reporting cycle of firms in Sri Lanka, and firm revenue was a significant determinant of the firm decision on SDGs incorporated sustainability reporting. Further, it was identified that a higher percentage of firms associated to the Food, Beverage and Tobacco industrial category reports more of their sustainability practices with regards to the global SDGs. It was further concluded that firm characteristics are less likely to influence the decision on SDGs in corporate sustainability reports in firms of Sri Lanka. Perhaps, it could be suggested that the firms could improve the incorporation of SDGs in corporate sustainability reporting cycle, and thereby make their firms reach a significant position in the market by changing the attitudes of the top managers and building up sustainability favorable organizational culture. As SDGs are an intergovernmental initiative, trade regulatory bodies could mediate in the process by designing policies to enhance the quality, and content of the sustainability disclosures and thereby lead towards a sustainable economy in future.

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# A review on organic liquid fertilizers and their potential impacts on the growth and yield of agricultural crops

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## Abstract

It is assumed that Liquid Organic Fertilizer (LOF) can serve as a supplement or an alternative to Solid Organic Fertilizer (SOF). They are made by soaking nutrient rich materials for several days or weeks to facilitate fermentation through microbial activity. The most common advantage affiliated to LOF is that its ability to serve as an immediately available source of nutrients ensuring fast uptake and provide short term rapid results for quick green up using a small quantity. The SOF contains nutrients in a solid form and that need to be dissolved or decomposed into soil solution before uptaken by the plants. The present study was conducted with the intention of evaluating the organic liquid fertilizers and their impacts on growth and yield of crops by reviewing the published literature. The review of literature under the present study has shown that there are many types of LOF including fresh plant extracts, liquid manure and liquid bio-fertilizer. They are extracted from wide range of materials and by methods especially using locally available materials. Hence, most of them can be home-made at a very minimal cost. Research studies conducted using organic liquid fertilizers have shown lot of positive impacts on crop growth, yield increase and quality and plant protection. Further, there are studies to formulate and test new forms of organic liquid fertilizers using natural substances. The study reveals that liquid organic fertilizers (LOF) can play an important role in sustaining crop growth and yield while making minimum impact on the environment.

Keywords: *Organic farming, liquid organic fertilizer, crop growth and yield.*

## 1. Introduction

Organic farming is a holistic way of farming with the aim of conserving the natural resources and safeguarding the soil from further deterioration. Ali et *al* (2011) stated that generally, it avoids use of synthetic fertilizers, pesticides, growth regulators and relies on green manures, crop rotations, crop residues, animal manures, organic fertilizers, and bio pesticides. According to IFOAM and FiBL (2017), 50.9 million hectares of agricultural land are organic and a total of almost 2.4 million organic producers are engaged in farming. Among that, more than three quarters of the producers are found in developing and transition countries. The largest number is reported from India followed by Ethiopia and Mexico.

Since the ancient time, organic fertilizer application has been considered as one of the most important techniques to increase and maintain soil fertility. And also it serves as a source of food for microorganisms living in the soil and increases the number and activity of those microorganisms, therefore, ultimately makes the land fertile (Hadisuwito, 2008). At the same time, farmers have used organic manure for centuries until chemical or inorganic fertilizers were introduced. They confer many benefits to the soil-plant system, which cannot be provided by inorganic fertilizers. However, this practice has been gradually neglected during the last few decades. As a result, physical, chemical and biological properties of soils have gradually degraded. Continuous application of inorganic fertilizer makes soil deteriorating and increases the cost of production, but organic manure maintains the sustainability and builds up soil fertility in favor of crops. Consequently, it ensures a steady release of nutrients to the crops as the organic matter breaks down. Organic materials particularly rice straw, cow dung, green manure, poultry manure and compost have traditionally been used by farmers in organic agriculture. The bulky organic manure contains low nutrient concentrations but liberal and continuous applications build up the organic matter and nutrient content of soil and increase crop production.

Based on above scenario, there are different types of organic fertilizers that can be successfully used to improve the long term soil fertility in many parts of the country. Generally organic fertilizer is made from organic materials. It can be in various forms like solid organic fertilizer (SOF) and liquid organic fertilizer (LOF). Globally there is prevalent use and scientific knowledge of solid organic fertilizers. In contrast, liquid organic fertilizers have largely remained in the background of mainstream scientific literature and little knowledge exists about them. Moreover, Solid Organic Fertilizer (SOF), as it contains nutrients in a solid form that will need to be dissolved or decomposed into the soil solution before the nutrients results can be seen, it requires moisture and time. Therefore, it is assumed that LOF can have the ability to serve as an alternative to SOF. With the special reference, organic based liquid fertilizers are a good choice for several purposes among other solid organic fertilizers since they bring the same benefit from small amounts of fertilizer. Many LOFs are nutrient rich material, which is soaked in water for several days or weeks to undergo fermentation.

With the improved agricultural technology, organic farmers are introduced with various methods to increase the efficiency of fertigation and ensure the fast uptake of nutrients using LOF. Accordingly, there are different types of liquid organic fertilizer and their differences are mainly in the raw materials used, forms of utilization and the sources of microorganisms (DOAE 2003, Higa and Parr, 1994). Liquid manures are made by fermenting plant material and then extracting in water. Those are designed in the form of liquid to supply the nutritional needs to crops. The dilution rates and ratios between multiple liquid fertilizers can be quickly activated to reflect the growth of the crops.

Liquid organic fertilizer can be used for sustainable farming by increasing the number of beneficial organisms in soil and plant surfaces as an organic approach to plant or soil care. Basically, locally available materials are used in the production of organic liquid fertilizers. There are many liquid fertilizers available for agricultural crops, both commercially prepared and home-made. Most are fast release nutrient sources that can be used anytime throughout the crop cycle giving the farmer a wide range of different combinations of major nutrients, trace minerals and growth promoting elements. Therefore, the proposed review was intended to review the published literature to study the organic liquid fertilizers. Further, this review has revealed and evaluated to identify the plant species and methods used to prepare organic liquid fertilizers and to identify the impacts of organic liquid fertilizers on growth and yield of agricultural crops.

## 2. Importance of Liquid Organic Fertilizers (LOF)

Natural liquid fertilizers have immense benefits for the soil and crop production. They add soil organic matter, improve soil structure and preserve essential nutrients that crops need in order to grow well.

As cited (Foth and Turk, 1972), if a soil is to produce crops successfully, it must have an adequate supply of all the necessary nutrients which plants take from the soil. If any of these elements are lacking, normal plant growth will not occur. It is supported by the statement of Onwueme and Sinha (1999) and Uwizeyimana (1997). In the context of organic farming, natural organic fertilizers provide a wide spectrum of plant nutrients and improve its soil physical properties. Furthermore, it encourages insects and worms to burrow into the ground thus improving permeability to a large extent.

Higa and Kanal (1998), examined the EM (Effective Microorganism) technology in agriculture. It is a liquid concentrate comprising very large numbers of such effective microorganisms that have been extracted from the natural world and coexist harmoniously in a liquid state. They concluded that EM technology maintains crop yields without the use of agricultural chemicals or artificial fertilizers, makes the method of farming less expensive and capable of producing high-quality products, produces high yield and preserves the environment.

Previous studies have already shown that the plants treated with organic liquid fertilizer produced higher yield than recommended inorganic fertilizer. Meg Howe (2017), defined, compost tea is a liquid version of the solid compost material. They contain soluble plant nutrients and a complex community of beneficial microorganisms. It also boosts the plant growth and soil enhancing activity of soil life. Compost tea has been used as a fertilizer, pesticide and fungicide.

Further, some studies conducted on the antifungal and antimicrobial properties of Gliricidia extracts, proved its ability to inhibit the growth of some fungi, bacteria and nematodes. Finding of Ganesan (1994) revealed that the foliage of Gliricidia is higher in its nutritional composition. According to Chatterji (2004), Seaweed extracts have nitrogen, phosphorus and higher amount of water soluble potash, other minerals and trace elements in a readily absorbable form by plants. It also controls deficiency diseases in plants if the concentration of seaweed extract is low. It has been used more effectively in the world in promoting plant growth. Moreover, wormy wash is recommended to spray in the diluted form, to fruit crops and vegetables at the flowering and fruiting stage. This will reduce flower drop. Wormy wash could be applied to the crop either as a plant growth hormone or as a fertilizer (Lionel Weerakoon, 2011).



## 3. Liquid Organic Fertilizers and their common method of preparation

The use of LOF in agriculture plays a great role in recycling essential plant nutrients, sustaining soil security as well as protecting the environment from unwanted hazards. Accordingly, at present many farmers are practicing alternative techniques to prepare liquid organic fertilizers (LOF). The preparation of LOF is easy, efficient to use and quick and not necessary to wait for long time. In this context, some researchers and scholars reported and showed that the preparation of some LOF is possible from locally available materials in the natural environment. Generally, there are many types of LOF including liquid manure, readily available fresh form and liquid bio-fertilizer. Detailed classification of LOF is given in the Table 01.

**Table 01: Detailed Classification of LOF**

| Type | Liquid Organic Fertilizer | Source | Common method of preparation |
|---|---|---|---|
| 1. Liquid manure | Leaf extract | Lionel weerakoon, 2011. | Fermentation of fresh plant materials in water |
| | Water-hyacinth extract | Simbarashe Govere et *al*., 2011 | |
| | Glliricidia extract | Peiris and Weerakkody, 2015 | |
| | Russian comfrey | Simbarashe Govere et *al*., 2011 | |
| | Pig weed red root | Simbarashe Govere et *al*., 2011 | |
| | Green tea | Kelly Martin, 2020 | |
| | Lawn and weed fertilizer | Robert Pavlis, 2021 | |
| 2. Readily available fresh form | Cow urine | Nelson Licinio C de Oliveira et *al*., (2009) | Use as a readily available fresh form or dilution is done before application of some crops |
| | Fish pond water | Stone, N.M. and Thomforde, H.K. 2004. | |
| | Human urine | Ranasinghe et *al*., (2015) | |

| | | | |
|---|---|---|---|
| 3. Liquid bio-fertilizer | Fish tonic | Lionel weerakoon, 2011. | Fermentation process (Extracting nutrients and micro-organisms) |
| | Fruit tonic | Lionel weerakoon, 2011. | |
| | Jeewamrutha | Lionel weerakoon, 2011. | |
| | Beejamrutha | Sreenivasa et *al*., 2009 | |
| | Panchagavya | Rathnayake et *al*., 2013 | |
| | Amutha karaikal | Lionel weerakoon, 2011. | |
| | Compost tea | Min Jeong Kim et *al*., 2015. | |
| | Compost tea | Meg Howe. 2017. | |
| | Food waste | Syeda Azeem Unnisa, 2015 | |
| | Seaweed extract | Ganapathy selvam and Sivakumar, 2014. | |
| | Wormy wash | Lionel weerakoon, 2011. | |
| | LOF from sugarcane pulp and sugarcane skin | Jajuk Herawati et *al*., 2017. | |
| | Shrimp extract | Rongting Ji et *al*., (2017) | |
| | Poultry manure extract | Peiris and Weerakkody, 2015. | |

## 4. Plant species used in preparation of LOF

The source of LOF have significant effect in the nutritional status of the organically managed mandarins. Conversely, these LOF have a great positive impact on plant growth, quality and as well as yield of crops. Many researchers proved the effect of LOF on agricultural crops. Therefore, for the benefit of higher production on agricultural crops, some plant species are used in the preparation of LOF. At the same time literature and particular researches are providing different opinions regarding different plant species used in organic agriculture sector which are shown in the Table 02.

**Table 02: Plant species used in production of liquid organic fertilizers**

| Plant Species | Scientific Name | Source |
|---|---|---|
| Water Hyacinth | *Eichhornia crassipes* | Simbarashe Govere et *al*., 2011 |
| Pig weed | *Amaranthus retroflexus* | Simbarashe Govere et *al*., 2011 |
| Gliricidia | *Gliricidia sepium* | Ganesan, 1994 |
| Russian Comfrey | *Symphytum officinale* | Simbarashe Govere et *al*., 2011 |
| Seaweed | *Hypnea musciformis* | Ganapathy Selvam and Sivakumar, 2014. |
| Sugarcane | *Saccharum officinarum* | Jajuk Herawati et *al*., 2017 |
| Moringa | *Moringa oleifera* | Sanjay Singh et *al*., 2013 |

| | | |
|---|---|---|
| Eupatorium | *Eupatorium perfoliatum* | Panda, 2013. |
| Tithonia | *Tithonia diversifolia* | Fahrurrozi et *al.,* 2015. |
| Erythrina | *Erythrina variegate* | Lionel weerakoon, 2011. |
| Leucaena | *Leucaena leucocephala* | Jayasundara et *al*., 2016. |
| Kappetiya | *Crotalaria retusa* | Rathnayake et *al*., 2013 |
| Lantana | *Lantana camara* | Lionel weerakoon, 2011 |
| Neem | *Azadirachta indica* | Joaquin Adolfo Montes-Molina, 2013 |
| Papaya | *Carica papaya* | Lionel weerakoon, 2011. |
| Banana | *Musa acuminata* | Lionel weerakoon, 2011. |
| Pumpkin | *Cucurbita maxima* | Lionel weerakoon, 2011. |
| Alfalfa | *Medicago sativa* | Robin Sweetser, 2017 |
| Clover | *Trifolium* | Robin Sweetser, 2017 |
| Horsetail | *Equisetum arvense* | Robin Sweetser, 2017 |
| Willow | *Salix alba* | Robin Sweetser, 2017 |
| Dandelions | *Taraxacum officinale* | Robin Sweetser, 2017 |
| Stinging nettle | *Urtica dioica* | Robin Sweetser, 2017 |
| Chicory | *Cichorium intybus* | Robin Sweetser, 2017 |

## 4. Effect of Liquid Organic Fertilizer on crop productivity in Sri Lanka

Addition of organic matter in the soil is a well-known practice to increase crop yields. Many researchers reported that an organically managed field ensures the sustainable usage of resources, high yield for crops without over reliance on costly inputs, and environmental and biodiversity protection. Although, many research studies showed positive impacts of LOF on crop growth, quality, yield and plant protection, in Sri Lankan context, a limited number of literature is available at present.

Rathnayake et *al.,* (2013) revealed that rice plants sprayed with jeewamrutha produced highest chlorophyll content, plant height, number of tillers, panicle initiation, percentage of thousand grain weight and total yield. As a result, they concluded that application of jeewamrutha is an alternative liquid fertilizer technique for farmers to get high yield with low cost.

Sutharsan and Rajendran (2010) examined the performance of organic liquid fertilizer (Jeevamrutha) on growth and yield of maize. Application of jeevamrutha once a week could increase yield of maize. It resulted in higher leaf area, biomass, number of grains per cob and yield during reproductive and maturity stages.

Peiris and Weerakkody (2015) concluded that the foliar application of Glliricidia leaf extract as the most favorable organic based liquid fertilizer for best growth performance of leaf lettuce compared to Compost tea and Poultry manure.

Further, Sutharsan, Nishanthi and Srikrishnah (2014) reported that Seaweed extract with 20% concentration of foliar application increased shoot dry weight, root dry weight, fruit number, fruit yield per hectare along with Total Soluble Solids and Total acidity content of fruit significantly over the control, while seaweed extract with 100% of foliar application reduced the above mentioned parameters significantly over the control in tomato plants. Therefore, they could conclude that the seaweed extract at 20% concentration level can be used to enhance the growth, yield and quality of tomato plants.

Human urine is a liquid waste rich in essential plant nutrients such as nitrogen, phosphorous and potassium. Ranasinghe et *al*., (2015) tested that to explore the possibility of utilizing human urine in edible crop production as a low cost and effective nitrogen fertilizer. It showed (human urine: nitrogen concentration adjusted to 20% more than the concentration) the highest increase in plant height, leaf area, root dry weight and total nitrogen content of leaves in bean plant and suggested that urine can effectively be used as a nitrogen fertilizer substitute in agricultural production.

## 5. Effect of Liquid Organic Fertilizer on crop productivity in other countries

Simbarashe Govere et *al*., (2011) tested the nutrient content of organic liquid fertilizers in Zimbabwe. They revealed that Water Hyacinth liquid manure contained significantly high N and P contents, indicating its suitability as a macronutrient fertilizer. All liquid manures had high K contents, particularly Russian Comfrey. Pig weed had high levels of Ca, Zn and Mg suggesting its suitability as a sufficient micronutrient fertilizer. As a result, they concluded that all liquid manures had NPK contents greater than common solid organic fertilizers such as legume green manure and cattle manure used in Zimbabwe.

Jajuk Herawati et *al.,* (2017) reported the performance of LOF obtained from sugarcane pulp waste and skin concentration on soybean yield. The results reported no significant effect of basic fertilizer doses treatment on soybean yield, while LOF concentration of 14.3% gave better result on growth and soybean yield.

Vijayanand et *al.,* (2014) explored that the bio fertilizing efficiency of seaweed liquid extracts of brown alga *(Sargassum wightii)* on the growth, biochemical and yield parameters of cluster bean plant. Results showed that Seaweed Liquid Extract (SLE) at low concentration (1.5%) exhibited better performance in growth and yield parameters. Meanwhile, it consisted of micro and macro nutrients, vitamins, growth hormones and other constituents, thus the extract might be very much useful to the crops but the concentration should be appropriate to enhance growth and productivity.

Syeda Azeem Unnisa (2015) reported that the food waste is a good source of nutrients and it can be processed into organic liquid fertilizer rather than throwing away. The experiment was conducted by conversion of food waste generated from restaurants, wedding halls and hotels into organic liquid fertilizer through anaerobic process.

Larisa Cremeneac and Tatiana Boclaci1 (2015) tested the impact of applying the liquid organic fertilizer obtained from wormy compost on quality of the maize. It was found that the soaking of maize seed in a liquid organic fertilizer obtained from crude worm compost and drinking water in the ratio of 1:100 and its use as a fertilizer contributed to the early emergence of corn and showed more intense physiological development, improved quality of maize, and increased the content of total nitrogen and crude protein content.

Panchagavya was tested for different crops such as turmeric, paddy, onion, gingelly, sugarcane, banana, vegetables and curry leaf and it was found that it enhanced the growth, vigour of crops, resistance to pest and diseases and improvement of keeping quality of vegetables and fruits (Natarajan, 2002).

Rongting Ji et *al*., (2017) reported that the application of shrimp extract in chrysanthemum produced the greatest increases in root dry weight, total length, surface area, volume, tips, and thick root length, respectively and significantly increased the nutrient contents also. Thus, It could be concluded that the liquid organic fertilizer of shrimp extract is an effective alternative to chemical fertilizer during the early stage of chrysanthemum growth.

Nelson Licinio C de Oliveira et *al*., (2009) evaluated the effect of cow urine on the growth and yield of lettuce. The increase in cow urine concentrations has increased the performance of all lettuce characteristics. The highest yield was obtained with the concentration of 1.25% applied on leaves and with 1.01 % applied to soil, increasing the yield by 28.1% and 47.3% respectively compared to the control.

Catello Pane et *al.,* (2014) reported that the use of compost tea (CT) is becoming interesting for applications in lettuce cultivation. Due to CT, commercial yield and the physiological and nutritional status of the lettuce plants increased, as noticed by foliar chlorophyll content assessment measured during crop cycles. The results provided encouraging indications about the practical application of CT in horticultural organic farming system.

Sivasangari Ramya et *al.,* (2015) revealed that lower concentration (1.5%) of liquid extracts of marine alga (seaweed extract) showed promoting effect on growth and productivity of brinjal plants. It can be concluded that seaweed extracts could be used as eco-friendly liquid biofertilizer to substitute chemical fertilizer and also it plays a pivotal role in organic farming practices toward sustainable agriculture.

In Jasmine, spraying two rounds of Panchagavya, one before the flower initiation and another during bud setting phase ensured continuous flowering and in annual moringa, spraying doubled the stick yield besides giving resistance to pests and diseases. (Vivekanandan, 1999).

Somasundaram et *al*., (2007) revealed that Biogas slurry with Panchagavya combination is adjudged as the best organic nutrition practice for sustainability of maize-sunflower-green gram system by its overall performance on growth, productivity, quality of crops, soil health and economics.

Joaquin Adolfo Montes-Molina et *al*., (2014) found that leaf extract of *Gliricidia sepium* stimulated tomato growth and altered the leaf and fruit characteristics. This was most likely due to its action as a growth regulator and or an inductor of changes in the tomato growth regulation, but not due to its action as an insect repellent. Consequently, leaf extract of *Gliricidia sepium* could be used to stimulate tomato development.

Mohanalakshmi and Vadivel (2008) revealed that ashwagandha plant sprayed with Panchagavya (3%) produced higher number of leaves per plant. Vennila and Jayanthi (2008) revealed that application of 100% recommended dose of fertilizer along with Panchagavya spray (2%) significantly increased the okra plant height and dry matter production.

## 6. Conclusions

The challenges faced by the Organic Agriculture sector are immense today. The growing agricultural practices ensure more fertilizers for higher yield. At present, wide spread requirement for the production of quality and healthy food to nourish the increasing population is in high demand. In this context, organic liquid fertilizer plays a great role in environment friendly agriculture. Therefore, in summary, this review has provided significant evidence of the important and positive aspects on the use of organic liquid fertilizer in cultivation of agricultural crops. Organic liquid fertilizers ensure the safety of agricultural practice without undesirable impact of chemical fertilizers and have a favorable effect on growth and yield of crops. In the result of studies it was found that generally all organic liquid fertilizers were of higher nutrient content than that of common solid organic fertilizers used by farmers. Thus, in the light of above analysis following conclusions can be made from this review.

- Many farmers are practicing alternative techniques to prepare liquid organic fertilizer from locally available materials in natural environment such as leaf extract, fish tonic, fruit tonic, wormy wash etc.

- The application of LOF, enhances growth and yield of agricultural crops compared to Solid Organic Fertilizers.

- The source of fertilizer has significant effect on the nutritional status of organically managed mandarins.
- Literature and particular researches are providing different opinions regarding different plant species used in production of liquid organic fertilizer.
- Plant growth substances in jeevamurtha and panchagavya help to bring rapid changes in phenotypes of plants and also improve the growth of plants.
- The use of liquid manures is an eco-friendly technique in order to enrich nutrient content of plant and to increase the growth, yield along with the quality of plants.
- Panchagavya, Jeevamruth and Beejamruth are cheaper ecofriendly organic preparations made by cow products namely dung, urine, milk, curd and ghee.
- Plant growth substances in seaweed extract, jeevamurtha and panchagavya help to bring rapid changes in phenotypes of plants and also improve the growth of plants.
- Some plant species (Gliricidia, Tithonia, Erythrina, Eupatorium, Leucaena, and Lantana) have insecticidal, repellent, rodenticidal, antifungal and anti-microbial properties.

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# Performance of biofilm enriched Eppawala rock phosphates over triple super phosphates in rice cultivation

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**Abstract**

Eppawala Rock Phosphates (ERP) has a greater potential to be used as an alternative for Triple Super Phosphate (TSP) if phosphorous (P) bio-solubility is increased. A certain biofilm (BF3) has been identified as the most efficient P bio-solubilizer for ERP. Thus, this study was designed to test the potential of biofilm-enriched ERP to replace the TSP in rice cultivation. Two experiments were conducted; soil leaching tube and pot experiments under controlled conditions. A modified chemical fertilizer ($CF_M$) mixture was developed by replacing TSP from ERP in the existing chemical fertilizer ($CF_E$) mixture for rice recommended by the Department of Agriculture (DOA). Nitrogen (N) and potassium (K), levels were maintained according to the DOA recommendation. Eleven treatments were used with all possible combinations of $CF_E$ and $CF_M$ at 50% or 100% rates alone or together with the BF3. Soil alone was used as the control. Treatment of 50% $CF_M$ + BF3 was denoted as biofilm-enriched ERP. The experiments were conducted in a Completely Randomized Design (CRD) with three replicates. Biofilm enriched ERP showed no added advantage over the $CF_E$, with lower cumulative solubilized

P in leachates. At the end of the pot experiment, biofilm-enriched ERP showed significantly ($p<0.05$) higher P retention in soil and significantly ($p<0.05$) lower grain yield compared to the $CF_E$. The overall results conclude that the biofilm-enriched ERP performed poorly in comparison to the DOA recommended TSP dosage. Thus, further studies are required to enhance the performance of biofilm-enriched ERP to use as an alternative for TSP in rice cultivation.

**Keywords:** *Biofilm, Eppawala rock phosphate, Rice cultivation, Triple super phosphate*

## 1. Introduction

Triple Super Phosphate (TSP) is the major P fertilizer in rice cultivation due to its high solubility and easy application. TSP is manufactured from rock phosphate excavated from the earth. Hence, TSP consists of many trace elements such as cadmium (Cd), nickel (Ni), copper (Cu), lead (Pb) etc. Further, the TSP contains Cd levels about 24 $\mu g\ g^{-1,}$ which is higher than the maximum permissible levels (10 $\mu g\ g^{-1}$) identified by the Sri Lanka Standards Institution (SLSI). In comparison, ERP contains about 1.92 $\mu g\ g^{-1}$ of Cd, much smaller than that in TSP (Premarathne *et al.,* 2011). According to a study conducted by Chandrajith *et al*. (2010), the agricultural fields where TSP has been used as the leading P supplement have recorded notable trace elements such as aluminium, chromium, nickel, cadmium, lead, and uranium. The results suggest that the long-term application of TSP can lead to contamination of soils with trace elements, highlighting the importance of finding an alternative P fertilizer in place of TSP. The ERP is considered a cheap and environmentally-friendly alternative to TSP, despite few constraints. Due to the low water solubility of ERP, its direct application as a P fertilizer has been limited to few perennial crops such as tea, rubber, coconut, export cash crops etc. Due to the slow release of P, ERP is not recommended for short-term crops (Appleton, 1994).

The solubility of ERP can be enhanced with Phosphorous solubilizing microorganisms (PSMs) present in biofilm mode. The National Institute of Fundamental Studies (NIFS) has developed biofilm formulations (BF1, BF2, BF3 and BF4) with bio-solubilizing ability of P in rock phosphates (Weerasundara *et al.,* 2014; Kumarihami *et al.,* 2015). Among them, BF3 was identified as the most effective biofilm formulation for bio-solubilization of ERP following a series of experiments conducted under laboratory conditions (Jayaneththi *et al.,* 2017). Thus, the present study was conducted to test the potential of replacing TSP with biofilm (BF3) enriched ERP in rice cultivation.

## 2. Methodology

### 2.1 Initial soil analysis

Paddy soils (great soil group Reddish Brown Earth, Order - Alfisols, Sub order -Ustalfs, Great group -Rhodustalfs) (Panabokke, 1996) were collected from a farmer field, Puliyankulama, Anuradhapura, and analyzed for pH with 1:2.5 soil suspension using a Fisher Accumet AB 15 pH meter. The soil sub samples (5g) were analyzed for available P (Murphy and Riley, 2002) using 100 ml of 0.5 M sodium bicarbonate extracts (Olsen *et al.,* 1954)), available N (Bremner, 1982) using soil extracts from 100 ml of 1M KCl. Exchangeable K was determined using soil extracts from 100 ml of 1M ammonium acetate (Matula,1996) employing inductively coupled plasma-optical emission spectroscopy (ICP-OES; Thermo I CAP 6500 Duo). Microbial biomass C of soils were determined by the chloroform fumigation-incubation technique (Jenkinson and Powlson, 1976; Vance *et al.,* 1988) and organic carbon by digestion with an acid dichromate solution and titrating with ferrous ammonium sulphate (Nelson and Sommers, 1982) at the commencement of the experiment.

### 2.2 Leaching Column Experiment

The leaching column experiment was conducted in the Soil and Water Science Laboratory at the Faculty of Agriculture, Rajarata University of Sri Lanka. Paddy soil (RBE) was collected from a farmer field at Puliyankulama in Anuradhapura, which belongs to the $DL_{1b}$ agro-ecological region with an average annual temperature of $27^0C$ and average annual rainfall of 1,368 mm.

#### 2.2.1 Preparation of treatments

Biofilm biofertilizer (BFBF) for rice reduces the application of DOA recommended level of N, $P_2O_5$ and $K_2O$ in chemical fertilizers (CF) by 50% (Seneviratne *et al.,* 2011), and hence, for the treatments 50% of $CF_E$ and $CF_M$ were used with the BFBF application, as explained in Table 1. In this study, BF3 was used as BFBF, since BF3 also acts as a PGP biofilm formulation (Weerasundara *et al.,* 2014; Kumarihami *et al.,* 2015). This prevented complicating the experiment, if two different biofilm formulations would have been applied separately to solubilize ERP-P and biofertilizer for the rice crop.

The biofilm-enriched ERP was developed by spraying BF3 on to ERP at a rate of 1.7 L per 100kg as recommended by the NIFS. The existing DOA chemical fertilizer ($CF_E$) for rice recommended in 2013 was modified ($CF_M$) by replacing TSP (22 kg $ac^{-1}$ /55 kg $ha^{-1}$) from BF3-enriched ERP (37 kg $ac^{-1}$/ 92 kg $ha^{-1}$ ). This replacement was done by considering the

$P_2O_5$ contents of fertilizers. The average $P_2O_5$ contents of TSP and ERP were taken as 46% and 27% respectively (Dahanayake, 1988). Eleven treatments were used in the experiment and they were arranged in a completely randomized design with three replicates for each treatment (Table 1).

**Table 1: The treatments used for the leaching tube experiment and pot experiment.**

| Treatments | |
|---|---|
| **T1** | 100% $CF_E$ |
| **T2** | 50% $CF_E$ |
| **T3** | 50% $CF_E$+ BF3 |
| **T4** | 100% $CF_M$ |
| **T5** | 50% $CF_M$ |
| **T6** | 50% $CF_M$ + BF3 |
| **T7** | 100% $CF_E$(only N,K) |
| **T8** | 50% $CF_E$(only N,K) |
| **T9** | 50% $CF_E$(only N,K)+ BF3 |
| **T10** | BF3 (only) |
| **T11** | Control (soil alone) |

**$CF_E$ -**DOA recommendation for (N,P and K)-TSP as the sole P source

**$CF_M$-** DOA recommendation for (N, P and K)- BF3 enriched ERP as the sole P source

**$CF_E$ (only N, K) -** DOA recommendation for (N and K)-only nitrogen and potassium

### 2.2.2 Leaching column study

Field soils and river sand were sieved (using a 2 mm sieve) separately before mixing them at a weight ratio of 1:1. The soil: sand mixture was sieved again using a 2 mm sieve before use them in the experiment. The leaching columns (50 ml) were filled with the 100g of soil: sand mixture and placed a glass wool pad (about ¼ - inch) on the soil surface to avoid dispersion. The initial weight of each column was measured and recorded. The measured amounts of fertilizers for the treatments were mixed thoroughly with 25 ml distilled water and added to each leaching tube. The rate of fertilizer applications (inorganic fertilizers and biofilm-enriched fertilizers) was aligned with the DOA and NIFS recommendations for rice (NIFS Annual Review Report, 2012). After adding of the treatments, columns were stoppered on top. Weights of all columns were measured once in 3 days and maintained the initial weight with the help of distilled water addition. The leachates were collected in two week intervals (Stanford and Smith, 1972) and analyzed for available P in leachates using molybdate-ascorbic acid method (Murphy and Riley, 2002). At the end of the study period (3 months), cumulative solubilized P was calculated. The soil remaining in the leaching columns were analyzed for biomass C using chloroform fumigation- incubation method (Jenkinson and Powlson, 1976; Vance *et al.,* 1998), soil organic carbon using acid dichromate digestion followed by titration with ferrous ammonium sulphate (Nelson and Sommers, 1982) and pH with 1.25 soil suspension using a Fisher Accumet AB 15 pH meter at the end of the 3 months.

## 2.3 Pot experiment

A greenhouse experiment was also conducted at the Faculty of Agriculture, Rajarata University of Sri Lanka. Thirty-three plastic pots (0.016 $m^3$) were used for 11 treatments in triplicate, and the pots were arranged in a completely randomized design. Each pot was filled with 1kg of paddy soil (RBE) collected from a farmer field, Puliyankulama, Anuradhapura, from a depth of 0-15 cm.

Following the DOA and NIFS recommendations (NIFS Annual Research Review, 2012), the inorganic and biofilm-enriched fertilizer treatments were broadcasted into pots since all fertilizers are in the form of powder (biofilm enriched ERP) and granular (TSP, Urea and MOP) forms. In each pot, three seedlings of *Oryza sativa* (BG 352 variety) were transplanted at equal distance. Initially, an equal amount of water (1 L) was added to each pot and then 500 ml of water was added daily until the panicle initiation. Other management practices such as weeding, pest and disease management were carried out according to the recommendations given by the DOA, Sri Lanka. During the study, the maximum temperature inside the greenhouse was about 40°C and the minimum was 28°C. After 14 weeks, the grain yield (per pot) was recorded. The soils in the pots were also analyzed for available P (Murphy and Riley, 2002) using 100 ml of 0.5 M sodium bicarbonate extracts (Olsen *et al.,* 1954).

## 2.4 Statistical analysis

The statistical analysis was performed using one-way ANOVA to determine the significant difference of P solubilization among treatments. The normality of data was tested using Shapiro-Wilk statistic under the UNIVARIATE procedure. SAS version 9.3 (SAS Institute, 2011) was used and the means were separated using Tukey's HSD test.

## 3. Results and Discussion

### 3.1 Initial Soil Analysis

Table 2 shows the properties of the soil samples collected from the farmer field, Puliyankulama, Anuradhapura. According to the results, the soil was low in organic matter content (1.65%), neutral in soil reaction (pH= 7.3), and it had a moderate level of available N. Available P content was close to critical or deficient level while K was at the sufficient level, but not int he optimum range for rice plant growth (Portch and Hunter, 2002). Soil microbial biomass of the studied samples was very low. This might be due to the intensive application of chemical inputs to the rice crop prior to this experiment.

**Table 2: Properties of soils collected from the farmer field, Puliyankulama, Anuradhapura.**

| Soil Property | Mean ± SD |
|---|---|
| pH | 7.3±0.09 |
| Available P (mg kg-1) | 14.31 ± 1.75 |
| Available N (mg kg-1) | 77.32 ± 0.34 |
| Exchangeable K (mg kg-1) | 102.6 ± 1.5 |
| Organic matter (%) | 1.65± 0.02 |
| Microbial biomass C (mg g-1) | 0.48± 0.06 |

### 3.2 Solubilized P in Leachate

The highest solubilized P was recorded in 100% CFE (T1) treatment at all sampling events, and it was significantly greater than the other treatments (Table 3). Further,100% CFE (T1) treatment solubilized P rapidly with an increasing trend (Fig. 1) compared to other treatments. The 50% $CF_M$ + BF3 (T6) showed lower P solubilization performance compared to 100% $CF_E$ (T1) throughout the study period.

**Table 3: Average solubilized P ($mg\ kg^{-1}$) of leachates.**

| | Average Solubilized P concentrations ($mg\ kg^{-1}$) ± SD | | | | | |
|---|---|---|---|---|---|---|
| | **2 Weeks** | **4 Weeks** | **6 Weeks** | **8 Weeks** | **10 Weeks** | **12 Weeks** |
| T1 | 0.070± 0.118 $^{a}$ | 0.074 ±0.116 $^{a}$ | 0.075±0.088 $^{a}$ | 0.079±0.061 $^{a}$ | 0.081±0.055 $^{a}$ | 0.092±0.185 $^{a}$ |
| T2 | 0.029±0.251 $^{e}$ | 0.045±0.025 $^{c}$ | 0.057±0.035$^{c}$ | 0.063±0.053$^{b}$ | 0.074±0.026 $^{b}$ | 0.076±0.190 $^{b}$ |
| T3 | 0.047±0.168 $^{d}$ | 0.044±0.104 $^{d}$ | 0.040±0.158 $^{e}$ | 0.034±0.081 $^{e}$ | 0.035±0.063 $^{i}$ | 0.025±0.190 $^{j}$ |
| T4 | 0.022±0.003 $^{j}$ | 0.012±0.003 $^{k}$ | 0.018±0.016 $^{j}$ | 0.031±0.002 $^{g}$ | 0.028±0.001 $^{j}$ | 0.028±0.003 $^{i}$ |
| T5 | 0.024±0.004 $^{i}$ | 0.028±0.002 $^{g}$ | 0.029±0.010 $^{g}$ | 0.031±0.001 $^{g}$ | 0.037±0.001$^{h}$ | 0.038±0.002 $^{h}$ |
| T6 | 0.026±0.002 $^{g}$ | 0.033±0.002 $^{f}$ | 0.034±0.007 $^{f}$ | 0.033±0.002 $^{f}$ | 0.043±0.003$^{f}$ | 0.044±0.003 $^{g}$ |
| T7 | 0.059±0.002 $^{b}$ | 0.049±0.002 $^{b}$ | 0.067±0.012 $^{b}$ | 0.059±0.001 $^{c}$ | 0.060±0.004 $^{c}$ | 0.068±0.002 $^{c}$ |
| T8 | 0.048±0.004 $^{c}$ | 0.044±0.001 $^{e}$ | 0.052±0.012 $^{d}$ | 0.054±0.003$^{d}$ | 0.058±0.001$^{d}$ | 0.062±0.006 $^{d}$ |
| T9 | 0.025±0.004 $^{h}$ | 0.025±0.001 $^{h}$ | 0.026±0.009 $^{h}$ | 0.027±0.001 $^{h}$ | 0.027±0.002 $^{k}$ | 0.030±0.006 $^{k}$ |
| T10 | 0.028±0.003 $^{f}$ | 0.015±0.002 $^{i}$ | 0.021±0.014 $^{i}$ | 0.030±0.002 $^{h}$ | 0.050±0.002 $^{e}$ | 0.060±0.008 $^{e}$ |
| T11 | 0.028±0.003$^{f}$ | 0.021±0.004 $^{i}$ | 0.034±0.003 $^{f}$ | 0.033±0.002 $^{f}$ | 0.041±0.003 $^{g}$ | 0.055±0.001 $^{f}$ |

According to Tukey's mean comparison test, different letters above each column are statistically significant at 5% probability level.

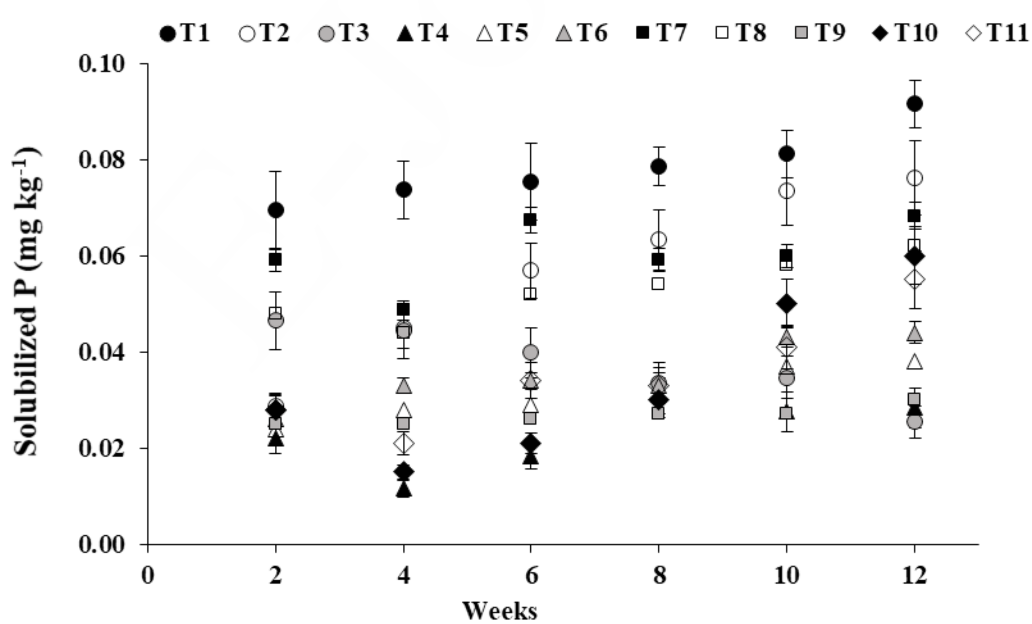


**Fig. 1: Solubilized P ($mg\ kg^{-1}$) of leachates in 2 weekly intervals**

### 3.2. Cumulative Solubilized P

Biofilms have been observed in many environments, but little is identified as P solubilizers. BF3 has proven its efficient solubilization of mineral P in ERP (Jayaneththi *et al.,* 2017). However, BF3 enriched modified CF mixture recorded significantly *($p<0.05$)* lower cumulative solubilized P than T1 (Fig 2). In every two weeks, significantly *($p<0.05$)* highest solubilized P content was recovered in TSP containing the existing CF mixture (T1) since over 90% of the total P in TSP is water-soluble and rapidly available for plant uptake.

Similarly, T1 or TSP containing CF has recovered significantly *($p<0.05$)* highest cumulative solubilized P at the end of the experiment. T6 or 50% $CF_M$+ BF3 also recorded significantly lowest cumulative solubilized P. Therefore, 50% cut down of chemical fertilizer with the biofilm application is not sufficient for soil collected from RBE, from a farmer field, Puliyankulama.

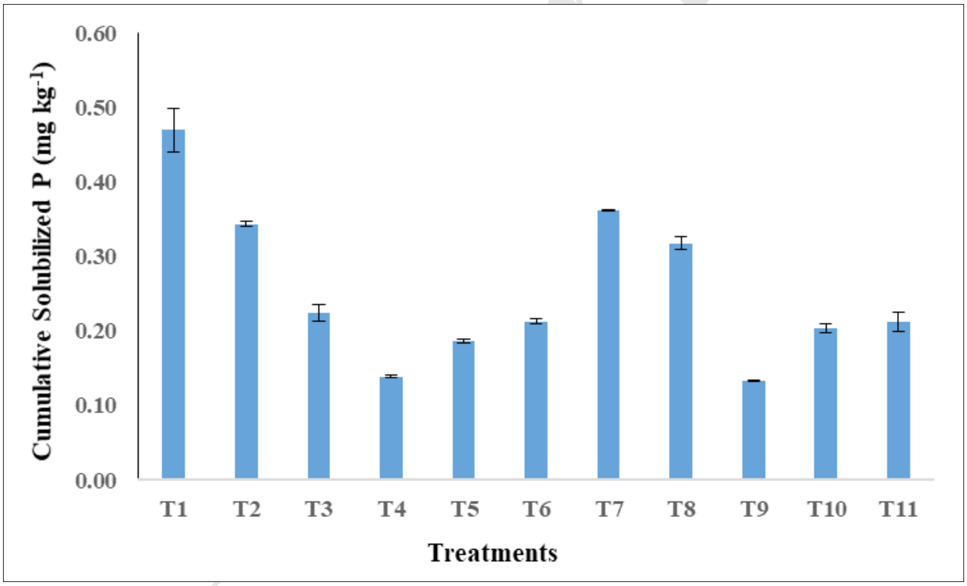


**Fig. 2: Cumulative solubilized P (mg $kg^{-1}$) of the leachates at the end of the three months of leaching tube experiment. According to Tukey's mean comparison test, different letters above each bar are statistically significant at a 5% probability level.**

### 3.3 P solubilizing Patterns

Tipple super Phosphate has several agronomic advantages that made it such a popular P source for many years. It rapidly releases the P for plants. Fig.3 clearly illustrates the P releasing rhythm of T1 or 100% TSP containing $CF_E$.

biofilm-enriched ERP to use as an alternative for TSP in rice cultivation.

**Keywords:** Biofilm, Eppawala rock phosphate, Rice cultivation, Triple super phosphate

**Fig. 3: Phosphorous solubilization rhythms of treatments: (a). T1 (100% TSP containing $CF_E$) and (b). T6 (50% $CF_M$+ BF3)**

The shelf life of microbes is the most critical point to mineral phosphate solubilization (Krishnaraj and Dahale, 2013). Phosphorous solubilization of biofilms varies with time. With the growth of microbes, solubilization was enhanced, and with the breakdown of fungal mass, solubilization was decreased. This process has happened up to the shelf life of microbes in biofilms. This nutrient release pattern is perfect for the plants and soils rather than the rapid release of nutrients as in T1.

Rapid mineralization rates of chemical fertilizers are not favorable for soil. It adversely affects the soil because it reduces soil P pool rapidly and the application of chemical fertilizer badly influences soil health and its quality, especially effects on soil pH, CEC etc. (Barak et al., 1997). Low mineralization rates help to maintain soil fertility level long term and increase soil health.



### 3.4 Biomass C, pH and organic matter

At the end of the 3 months, all the biofilms incorporated treatments, T3 (50% $CF_E$+ BFBF, T6 (50% $CF_M$ + BF3), T9 (50% $CF_E$(only N,K)+ BF3) and T10 (BF3 only) showed significantly higher microbial biomass C contents compared to other inorganic fertilizer only applications in T1, T4, T5, T7 andT8(Fig. 4 a). Further, applying inorganic fertilizer only treatments and the control decreased the soil microbial biomass C considerably from its initial microbial biomass C levels prior to commencing the experiments (0.48 mg $g^{-1}$) (Table 2).

At the end of the three-month study period, soil reactions of all treatments changed from the initial neutral pH (pH=7.3) level to slightly acidic (Table 2). Relatively higher acidic pH (5.43) was recorded with the biofilm alone applications (T10) (Fig. 4 b). Phosphorous solubilizing biofilms solubilize calcium bound P by excreting organic acids, accompanied by a drop in pH that results in the acidification of microbial cells and their surroundings (Tallapragada and Seshachala, 2012). Acidity directly influences the activity of microbes that are involved in the solubilization of insoluble inorganic phosphates.

The initial soil contained 1.65% of organic matter (Table 2), and the application of biofilms enhanced the organic matter contents in the soil over time. According to Fig. 4 c, treatments with biofilms (T3, T6, T9) showed significantly *($p<0.05$)* higher organic matter contents than the treatments of chemical fertilizer only applications.

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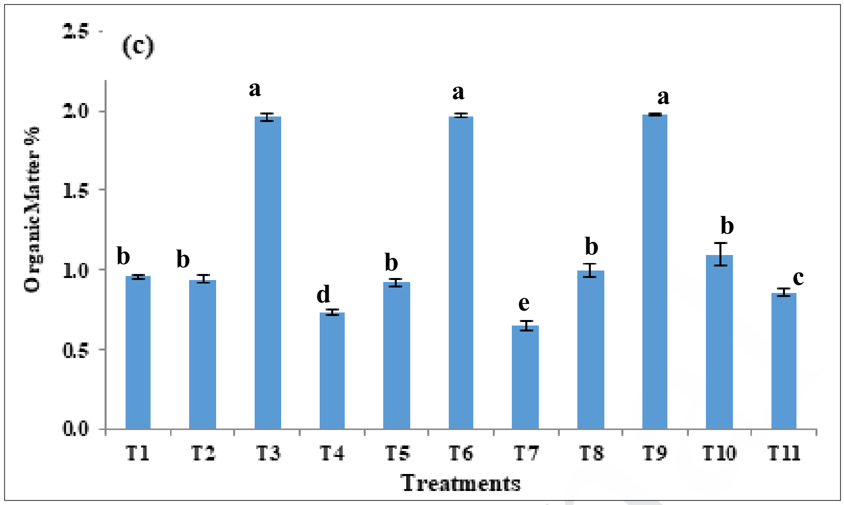


**Fig. 4: (a) Biomass, C (b) pH, and (c) Organic matter content of soils remaining in leaching tubes at the end of the three months. Different letters above each bar are statistically significant at 5% probability level according to the Tukey's mean comparison test.**

### 3.5 Available P in potting soils and grain yield

The soil used in this study initially contained 14.48 mg kg-1 of available P. Fig. 5 shows the available P levels in potting mixtures of different treatments after the 14 weeks (harvesting stage).

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## 4. Conclusions

This study was conducted to test the potential of biofilm-enriched ERP to replace the TSP in rice cultivation. However, the results of this research suggest that biofilm enriched ERP (50% CFM + BF3) shows no added advantage over the full dosage of TSP (100% CFE) on P supply to the rice plant. Moreover, it can be concluded that biofilm enriched ERP performs poorly compared to the DOA recommended TSP dosage in rice cultivation under controlled conditions. However, all the biofilms applied treatments significantly contributed to enhanced soil quality compared to other treatments. Therefore, further studies should be conducted by changing different ERP rates in the modified CF mixture and BF3 in greenhouse and field conditions.

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# Environmentally sustainable approaches for the utilization of agricultural wastes for ensuring global food security: A review

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**Abstract**

Increasing population and urbanization have significantly enhanced the global demand for food. Hence, with intensified farming, it has been estimated that the global waste will increase by 70% in 2050, and the contribution of agricultural waste to the total waste matter would be significant. Presently, the annual global agricultural waste generation is 998 million tons and if not treated and properly managed it would be challenging to maintain environmental sustainability. Therefore, it's timely to investigate agricultural waste management techniques that will ensure food security and environmental sustainability. Hence, this study was conducted based on a comprehensive literature review on strategies for agricultural waste utilization, its novel technologies, and its environmental concerns and potentials in safeguarding global food security with the aim of presenting potential approaches for utilizing agricultural wastes to enhance food security and environmental sustainability and its future perspectives. Improper waste disposal, lack of awareness, and government policies are the main reasons for the unprecedented waste generation globally. On-farm compost production, use for animal feeding, production of energy was identified as conventional approaches for agricultural waste utilization, while bioremediation, extraction of phytochemicals, and smart-waste management technologies were identified as novel approaches for the farmers to diversify their agriculture activities. However, many of the novel technologies are lack in practice due to several limitations. Hence, this study identified the importance of future research on novel approaches and expanding knowledge on existing technologies as promising moves to enhance sustainable agricultural waste utilization in the future.

**Keywords**: *Agricultural wastes, Environment, Food security, Sustainability*

## 1. Introduction

Agricultural waste can be defined as the waste generated during the production and processing of agricultural products, including crop waste, animal waste, processing waste, and hazardous waste (Obi et al., 2016). In recent years agricultural wastes have become an increasing concern with their excessive generation. Rapid population growth and urbanization have increased the demand for food, which produces large quantities of agricultural wastes (Harshwardhana & Upadhyay, 2017). Expanding agricultural production to meet the increasing food demand naturally has resulted in large quantities of livestock waste, agricultural crop residues, and agro-industrial by-products (Agamuthu, 2009). Besides, improper methods of waste disposal, irrational application of intensive farming methods, and abuse of chemicals in farming due to lack of awareness, poor government policies, and insufficient resource utilization also can be considered as major reasons for the excessive agricultural waste generation in the global scale (Rout & Sahoo, 2017). Even though the world has technologically developed, most agricultural operations still use conventional waste disposal practices such as open dumping, burning, and directing to septic ponds without having proper management (Sindhu et al., 2015). As a result, to the 2 billion tons of total waste-producing annually around the world, agricultural waste contributes by 998 million tonnes and, it causes significant negative impacts on the environment and sustainable development (Rout & Sahoo, 2017. Millati et al., 2019). According to Food and Agricultural Organization (FAO), food waste accounts for a large amount of agricultural waste generating around the world each year, and food waste and loss contribute to the global hunger crisis, with close to 800 million food-insecure people. The carbon footprint of food produced and not eaten is estimated as 4.4 gigatons (billion tons) of $CO_2$ equivalent (FAO, 2013). However, the waste generating from agricultural activities has a good potential to utilize as a source of energy (Harshwardhana & Upadhyay, 2017). Therefore, this paper compares and evaluates different agricultural waste management methods while highlighting the potentials for effective agricultural waste management and utilization to enhance global food security and environmental sustainability.

## 2. Methodology

The study was conducted based on a comprehensive review of the existing literature on strategies for agricultural waste utilization, its novel technologies, and its environmental concerns and potentials in safeguarding global food security.

## 3. Results and Discussion

### Classification of agricultural wastes and their generation

Agricultural wastes can be mainly classified into two major categories called non-biodegradable wastes and biodegradable wastes. Accordingly, the non-biodegradable agricultural wastes include discarded pesticide containers, plastics, bags and sheets, tires, batteries, clinical waste, old machinery, oil, packaging waste, etc. Biodegradable agricultural wastes include crop residues, slurries, and manure (CIWM, 2020).

Even though numerous individuals suffer from hunger, the quantity of world waste products increases day by day. It's been predicted that the number of waste products created has double the potential to feed those suffering populations. It has been calculated that about 30 percent of the world's food is wasted during production and processing, and about 16 percent of food is wasted by retailers and consumers (Statista Research Department, 2016). The main reasons for the food loss in many developing countries are inadequate storage facilities, lack of smart transportation systems, or refrigeration, while in developed nations, food is often thrown away due to oversupply from retailers or expiring due to not consuming on time (FAO, 2017). Further, with the increasing global food demand, agricultural development has coupled with the irrational application of intensive farming methods and intense utilization of chemicals (fertilizers, pesticides, herbicides, etc.) in cultivations (Dien & Vong, 2006). However, when persistently applied, it accumulates in the soil causing harm to beneficial organisms. Due to the higher water solubility of pesticides and fertilizers, they may also leach and enter into the sources of water and food products. This will lead to serious health risks in humans, including cancer, Parkinson's disease, Alzheimer's disease, congenital disabilities, and reproductive disorders (Mostafalou & Abdollahi, 2013).

Animal wastes incorporated with dairy shed gushing (pee, fertilizer, wash water, lingering milk, and wasted feed), dairy excrement, poultry litter (a blend of manure, water, spilled feed, plumes, and bedding material), renderings, and different squander from animals' operations is the other principle wellspring of farming waste that is needed to oversee appropriately (Balaman, 2019). The amount and the nature of the animal waste vary with the kind of animal species. In any case, the expanding demand that requires a higher measure of animal production has prompted numerous ecological and biosecurity issues

(Ogbuewu et al., 2012). Furthermore, harvesting and processing of aquacultural produce generate huge volumes of waste, and it has been estimated as 35-80% of the total animal waste. Aquacultural wastes include catch and rejects from fish harvesting, and processing waste generated from de-heading, deskinning, deboning, evisceration, washing, trimming, peeling, and filleting operations (Ghaly et al*.,* 2013). The non-natural agricultural wastes like agricultural plastics, tires and other hazardous substances generating from agricultural activities have caused huge environmental issues due to improper waste disposal methods (Cavanagh et al*.,* 2014). Consequently, the expanding quantities of agricultural waste result in several environmental problems, including air pollution, water pollution, soil pollution, loss of biodiversity, etc. (Sharma et al., 2019a).

In each year, billions of agricultural wastes are generated in developed and developing countries in the world (Yevich & Logan, 2003). The largest quantities of agricultural waste are generated from China among the Asian and Pacific region countries. In China, rice, corn, and wheat production generate 587 million tons of residues annually, and India is considered the second most agricultural waste generating country in Asia (Prasad et al., 2020). In Malaysia, agricultural wastes mainly generate rice, palm oil, rubber, coconut, and forest products, and it accounts for disposing of 1.2 million tons of agricultural waste into landfills annually (Agamuthu, 2009., Koopmans & Koppejan, 1997). In Sri Lanka, agricultural waste is mainly comprised of waste from paddy cultivation (paddy husk and straw), animal waste, coir fiber, and coir dust from coconut cultivation and bagasse from sugarcane cultivation, etc. and contributes to 6.4% of the total municipal solid waste (Premachandra, 2006). Table 1 summarizes the agricultural waste generation rate in Asian countries.

**Table 1: Agricultural waste generation rate in Asia (modified from Agamuthu, 2009).**

| Country | Agricultural Waste Generation Rate (kg/cap/day) |
|---|---|
| **Sri Lanka** | **0.3-0.14** |
| Japan | 0.17 |
| Singapore | 0.165 |
| Korea | 0.15 |
| Malaysia | 0.122 |
| China | 0.12 |
| Indonesia | 0.114 |
| Thailand | 0.096 |
| Vietnam | 0.092 |
| Myanmar | 0.068 |
| Nepal | 0.060 |
| Bangladesh | 0.04 |

Rice straw, Sugarcane, Wheat, and Corn are the four major crops cultivated in the world that account for a high level of global agricultural production (Saini et al., 2015). Therefore, these four crops are responsible for generating the majority of agricultural waste in the world. Asia accounts for the highest global production of rice straw and wheat straw, while America produced the highest quantities of corn stover and sugarcane bagasse (Ali et al., 2019). Figure 1 illustrates the global availability of the above four major agricultural wastes

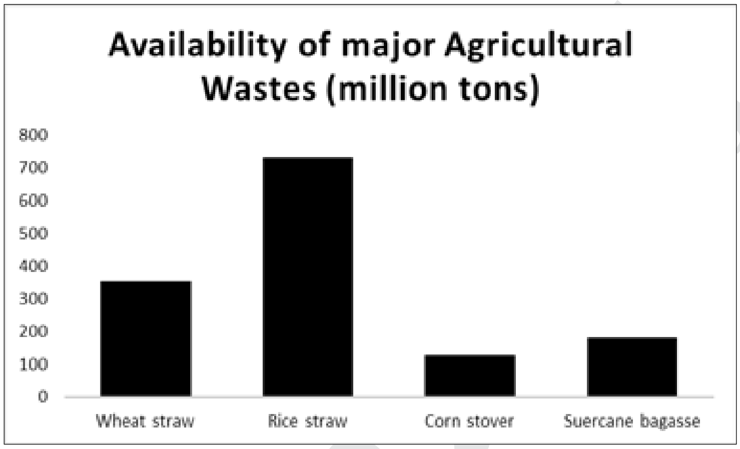


**Figure 1: Globally Available major agricultural wastes (modified from Saini et al., 2015).**

**Agricultural wastes and the environment**

The same as the other facets of development activities agriculture has become a major source of environmental pollution and waste generation. Therefore, it is important to draw our concern towards the minimization of waste generation and proper management of agricultural waste to achieve environmental sustainability (Nagendran, 2011). The impact of agricultural waste on the environment depends on two factors: the amount of agricultural waste generated and the method of disposing of the agricultural wastes. Generally, agricultural wastes are generated from several sources, notably from cultivation, livestock, and aquaculture (Loehr, 2012). Improper agricultural waste management practices such as open dumping, residue burning, and directing of wastes to natural waterways can be considered primary reasons for the environmental pollution associated with the agricultural waste (Rout & Sahoo, 2017). Agricultural waste burning releases pollutants such as carbon monoxide, nitrous oxide, nitrogen dioxide, and particles (smoke carbon) which are considered greenhouse gases. Emission of greenhouse gases and global warming, climate change, and destruction of aquatic ecosystems due to conditions like eutrophication caused by improper agricultural waste management has become a barrier towards the development of environmental sustainability (Levine, 1994). However, reducing, reusing, and recovering agricultural wastes enhance environmental sustainability by avoiding the addition of burden to the environment through the production of unnecessary materials that could be reused, conserving valuable natural resources while reducing the pollution and creating less waste, and extending the life of existing landfills (Rathi, 2006).

Livestock production is considered a major contributor to global warming, and it causes 35-40% of global anthropogenic methane and 9% of global anthropogenic $CO_2$ emissions. Further, livestock farming contributes to 65% of global nitrous oxide anthropogenic emissions which is considered as the most potent of the three major greenhouse gases. Enteric fermentation and manure constitute 80% of the methane emission while manure and urine cause 64% of global anthropogenic ammonia emissions. Hence, livestock waste is a major agricultural waste that creates adverse impacts on the environment (Abbasi & Abbasi, 2016). Besides, landfills are the largest man-made contributors of methane emissions to the atmosphere. When organic waste is disposed of without composting, it ends up in a landfill, producing large quantities of methane under anaerobic conditions (Gollapalli & Kota, 2018). Methane is considered a greenhouse gas that is 72 times more potent than $CO_2$ (Nyman, 2014). However, it has been predicted that the proper manure handling, biogas plants, crop burning ban, and reduction of aquatic contamination from agricultural wastes together can reduce 28% of global greenhouse gas emissions (Cooper et al., 2013).

Biogas production refers to the process of digesting organic waste anaerobically to produce an excellent fertilizer and combustible gas by disposing of agricultural residues, aquatic weeds, animal and human excrement, and other organic matter is considered a good source of clean, renewable energy. Biogas is a combination of methane (60-70%) and $CO_2$ (30-40%), which, if released in a non-combustible form, is harmful to the environment (Usman & Ekwenchi, 2013). Therefore, in addition to the production of renewable energy, controlled anaerobic digestion of animal manures reduces greenhouse gas emissions, nitrogen, and odor from manure management and intensifies the recycling of nutrients within agriculture (Zafar, 2018). Further, composting is also considered a sustainable approach for producing an organic fertilizer while reducing the quantity of waste generation and the potential pollutants. However, it has been revealed that composting has some pollution-associated problems despite these positive impacts (Shephered et al., 2000). The main pollution problems of composting include the emission of gases or volatile compounds into the air and the leaching of pollutants into groundwater. Therefore, to avoid these unfavorable impacts on the environment, it is needed to facilitate optimum conditions for the process of composting while ensuring the proper raw material selection, which determines the C/N ratio, optimum moisture condition and porosity, management of the compost heap, and the pile including the water addition, covering and the frequency of turning. Moreover, maintaining optimum maturation time is also very important to control the gas emissions and leaching problems (Schenk et al., 1996).

However, the main goal of agriculture is to meet the existing global food demand with the surplus amount of food production for exporting and future purposes. Therefore, with the increase of the agricultural output, chemical fertilizers, pesticides usage have also increased. Although the application of chemical inputs serves as a boon by increasing agricultural yields, it creates long-term negative impacts on the environment and human health (Abhilash & Singh, 2008). Higher levels of these contaminants from agricultural waste in soil and consequent plant uptake may affect public health, causing diseases like skin allergies, cancer, disorders of the central nervous system, etc. (Sharma et al.,2019b). The Chronic Kidney Disease of undetermined cause (CKDu) is affecting agricultural communities in Central America, South Asia, and possibly other parts of the world can be denoted as one of the severe health issues of agricultural wastes (Weaver et al*.,* 2015). Various possible causes have been suggested for CKDu, including pesticides and fertilizers mainly TSP, which contain a high amount of arsenic like potentially toxic trace elements (Jayasumana et al*.,* 2015). Annually a large amount of chemicals is adding to the agricultural soils in terms of fertilizers and pesticides like herbicides, insecticides, and fungicides weedicides and the residues of these applications may increase the levels of heavy metals while polluting almost every part of the environment including soil, water, land, and air (Atafar et al., 2010). The fertilizers and manure used in agriculture may cause detrimental effects on the environment. For example, fertilizers and manure used in agriculture contain a high amount of nitrate and phosphates, these nutrients can be washed into nearby water bodies (Savci, 2012). High levels of nitrogen and phosphorus in water bodies can cause eutrophication. This may result in hypoxia ("dead zones"), causing fish kills and decreased aquatic life. Excess nutrients can cause Harmful Algal Blooms (HABs) in freshwater systems, which disrupt wildlife and produce toxins harmful to humans (Le et al., 2010). Thus, every year millions of fertile soils are lost due to synthetic fertilizers, pesticides, and herbicides combined with other farm practices. The chemicals contained in pesticides can cause long-lasting damage to the soil. This can gradually alter the soil microbial activities, soil chemistry and finally deplete the soil fertility (Joko et al*.,* 2010).

Hence, organic agriculture can be considered a holistic production and management approach that supports the environment, health, and sustainability (Dubey, 2013). Organic farming is mainly based on minimizing the use of external inputs like synthetic fertilizers, pesticides, and on-farm resources efficiently for sustainable food production (Van Grinsven et al., 2015). There, agricultural waste can be used as an on-farm resource. Compost produced from agricultural wastes and sewage sludge, agro-industrial sludge, slaughterhouse sludge, and pig slurry digestate is some of the on-farm agricultural wastes that mainly use in organic farming. (Sharma et al*.*, 2019b).

Rapid urbanization and industrialization have led to the increasing disposal of potentially toxic trace metals into the environment (Wong et al., 2006). According to various researchers, low-cost agricultural waste such as rice husk, sawdust, sugarcane bagasse, coconut husk, oil palm shell, neem bark, etc., can be used in the elimination of most hazardous potentially toxic trace metals (Cr, Ni, Cu, Zn, Cd, Pb, Hg, and As) (Obi et al., 2016). Furthermore, bioremediation techniques that utilize the biological mechanisms of fungi, bacteria, and plants to degrade, transform, accumulate, or mineralize a pollutant to a nontoxic state can be effectively utilized to treat agricultural wastes at the farm level or in locations of accumulation (Evans, 2018).

**Agricultural wastes for enhancing food security**

Global food security can be achieved when all people at all times have adequate physical and economic access to enough safe and nutritious food to meet their needs for a healthy and active life (Clapp, 2014). Feeding 9 billion people globally is a great challenge and requires changes in agricultural production and management practices (Stefanis, 2014). Further, in 2050 the projected world population is 9.7 billion and it will enhance the global food demand by 71% than today (Cole et al., 2018). Therefore, as a strategic solution to this issue, it is necessary to take appropriate steps to convert agricultural wastes into a resource that could be utilized effectively without being discarded. Agricultural waste can enhance food security by converting waste to biofertilizer and organic substrates, energy, and through use as animal feeds (Amoding, 2007).

Production of bio-compost by utilizing agricultural wastes, including food wastes from fields to market, can be regarded as a much effective way to supply precious nutrients back into the soil while reducing the agricultural wastes in landfills (FAO, 2013). Crop residues, animal excreta, fruits and vegetable waste, grains, cereals, eggshells, dairy waste, etc. can be used for the process of composting. When drawing concern on the role of composting towards enhancing global food security, it improves the soil properties associated with plant growth and improves the nutritional content and the productivity of the crops grown in compost-rich soils while ensuring food security. Besides, composting replaces the application of chemical fertilizers, pesticides, and herbicides and it is essential for the production of quality agricultural products for the food industry (Shilev et al., 2007).

The utilization of agricultural wastes like straw, sugar cane by-products, and fruits and vegetable by-products for animal feeding is another best practice to enhance food security especially through increasing dairy animal productivity (Sruamsiri, 2007). Dairy farmers most commonly use rice straw to feed animals during the dry season when no green forage is available. During this period, farmers will have to supplement more concentrates to animals to get higher milk yields. However, urea or ammonia-treated rice straw is considered as a low-cost and effective solution to increase animal production during this season (Promma et al., 1993). Furthermore, it has been predicted that when the animals were fed with soya bean pod husk, a by-product of soya bean oil and meal industry, it has significantly increased the milk fat production of dairy animals (Sanitwong et al., 1997). Besides, pineapple wastes which consist of a crown, core, peel, leaves, and waste from flesh trimming can be used for cattle feeding due to its high palatability. It has been reported that the dried pineapple waste and ensiled pineapple waste can be used as supplemental roughage and can be replaced 50% of roughage in the total mixed ration for dairy cattle without adversely affecting the animal production (Jitramano, 2005). The by-products of the sugar cane industry, including sugarcane tops, sugarcane leaves, bagasse, and molasses, can also be used effectively for animal feeding due to their high nutrient contents. Especially, the sugarcane silage can be effectively used as a roughage source in cattle fattening diets and as a winter supplement for producing brood cows (Pate et al., 2002).

Production of energy from agricultural residues enhances food security by providing a valuable by-product, good quality fertilizer which improves the crop yields while providing additional revenue (Usman & Ekwenchi, 2013). Besides, agricultural wastes can be used as substrates for fruit, vegetable, and mushroom production. Cultivation of fruit and vegetable crops such as strawberry, pepper, tomato, cucumber, and okra on compacted rice straw bales in open fields or under greenhouses is a promising method to utilize rice straw residues towards enhancing food security. Further, the application of rice straw for the plantation of mushrooms is a well-known technique that has become increasingly popular in recent years (Abou Hussein & Sawan, 2010). Furthermore, spent mushroom substrate, which is a residue generating during the production process of mushrooms, can also be used as compost, as a substrate for other mushroom-forming fungi, as an animal feed, to promote the health of animals, and to produce biofuels and enzymes (Grimm & Wösten, 2018).

Recently, researchers have paved their attention towards the potentials for utilizing agricultural wastes for food value addition. Accordingly, they have identified the extraction of phytochemicals from agro wastes as a sustainable means of agricultural waste utilization. In that regard, dried mango (*Mangifera indica*) leaves have been used for the extraction of the phytochemical mangiferin that acts as a valuable biomolecule in the food and pharmaceutical industry (Rao and Rathod, 2018). Furthermore, recent studies have extracted and identified phenolic compounds such as flavonoids, amino acids, tannins, ascorbic acids from tomato leaf waste, underutilized crops like *Ficus racemose,* etc. Accordingly, it was proved that the extraction of phytochemicals from agricultural wastes, as a sustainable approach for utilizing agricultural wastes for food value addition (Sharma et al., 2020; Arab et al., 2019).

**Smart agriculture and waste management**

The agricultural sector is currently facing a wide range of challenges, while its role in human existence grows more vital with the increasing global population. Growing populations increase the demand for food, while at the same time, arable landscapes are shrinking due to urbanization (Campbell et al., 2014). However, it is essential to optimize agricultural productivity to meet the rising food demand parallel to the population growth. Therefore, smart agriculture can be regarded as an approach that focuses on farming operations that enhance productivity while reducing greenhouse gas emissions (Andrieu et al., 2017). Accordingly, Climate Smart Agriculture (CSA), precision farming, and ecological monitoring, with the use of Internet-of-Things (IoT), sensors, and servers can be considered as the key elements of a smart agricultural framework and it could be successfully integrated into a smart agricultural waste management system (Bong et al., 2018).

When considering the smart agricultural systems sound management and disposal of agricultural waste are of key importance to achieve food security and environmental sustainability. A smart agricultural waste management approach can be enabled by implementing IoT network sensors and cloud computing at each level from waste generation to disposal (Ojha et al., 2015). A simplified structure of an IoT-based smart waste management system is shown in figure 2.

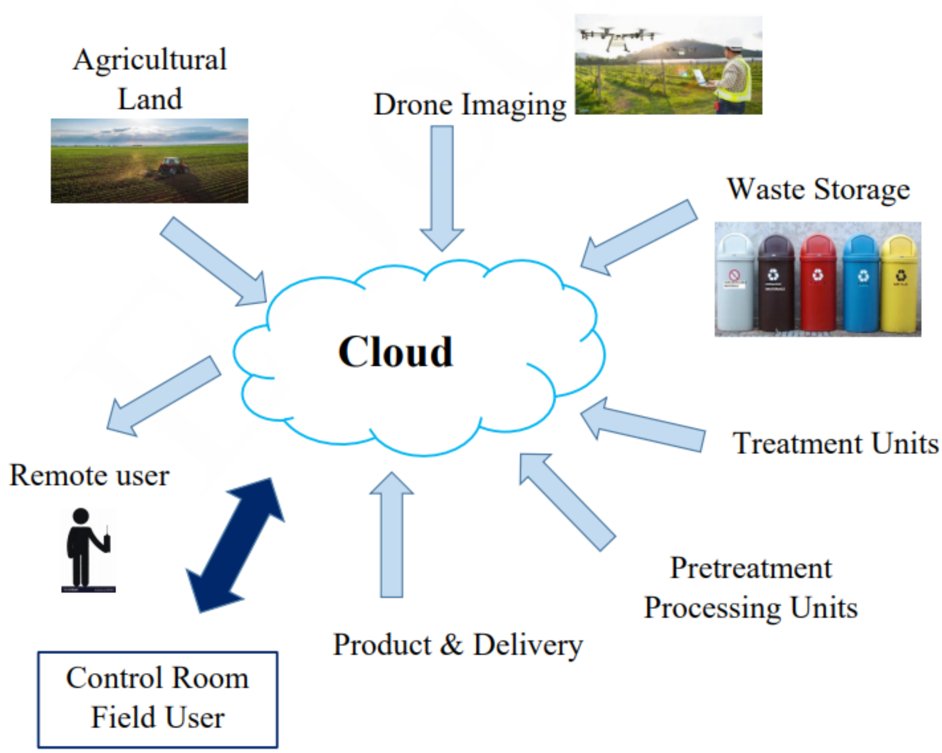


**Figure 2: A simplified structure of an IoT-based smart waste management system (Modified from Bong et al., 2018).**

The smart waste collecting bins equipped with Radio-Frequency Identification (RFID) tags and Global Positioning System (GPS) modules is a novel technology that has been introduced to farmlands. In this system, signals are sending for "smart" trucks when the bins are a quarter to full. The bins are weighed, and the reading is transmitted to the cloud that can be assessed among users. The waste pre-treatment unit will convey the signal regarding their treatment capacities. Upon receiving such information, the suitable amount of agricultural waste could be transported to the waste pretreatment unit by the trucks (Ward et al*.,* 2008). Moreover, the concept of intelligent disposal through a design that uses solar energy to feed the system and presence sensors for monitoring the amount of waste accumulated inside the collecting bins is another inventive technology that can be integrated into agricultural systems to reduce the emissions, contaminations, and reach sustainability (Saha et al., 2017). The waste pre-treatment technologies are also significantly important when implementing smart waste management concepts. Generally, in smart waste management systems, waste pretreatments units are equipped with technologies to convey the signal regarding their treatment capacities. In these systems, pre-treatment technologies such as alkali pre-treatment, thermal and thermos-chemical, ultrasonic pretreatment, etc. are commonly applied to break down the recalcitrant polymers via physical, thermal, or chemical treatment (Ward et al., 2008). Furthermore, IoT systems permit a platform for precision agriculture and ecological monitoring by enabling functions such as smart spraying and irrigation, assessment of the marine environment, and real-time data on queries, statistics, and abnormality warnings Hence, it facilitates the optimization of agricultural inputs, monitoring for sound collection, transportation and disposal of agricultural wastes and identifying potential illegal disposal or emergency, such as the spilling of waste (Wen et al., 2018). Accordingly, due to the real-time and continuous acquisition and analysis of decisive variables, smart technologies allow the identification, monitoring, improvement, and optimization of various components and the design of the supply chain, and it aids in the generation of desired products with optimum quality and quantity. Therefore, promoting smart agriculture with a smart waste management perspective will reduce waste generation and associated food losses while mitigating the adverse impacts on the natural ecosystems (Bong et al., 2018).

Further, IoT systems can be used for livestock management, crop growth monitoring, and soil analysis. Accordingly, it has been predicted that intensified livestock farming will enhance meat and milk productivity by 30% depending on the region while contributing to a 10% decrease in all agricultural emissions (Campbell et al., 2014). Besides, the IoT system includes sensors for soil moisture, nutrients, and air quality analysis which has the potential to optimize the crop and animal produce while reducing the quantity of waste generation. Hence, smart farming will boost the harvest while minimizing the usage of chemical fertilizers and it will be much beneficial to achieve the sustainable development of a nation (Parker, 2018).

**Future perspectives for agricultural waste utilization**

Even with the existing technologies, the continuous generation of massive quantities of agricultural wastes remains an unsolved global issue. Hence, it is important to draw global attention towards the future perspectives of agricultural waste utilization (Duque-Acevedo et al., 2020). Accordingly, Malucelli et al., (2017) investigated future perspectives towards the utilization of agricultural industrial residues for nanocrystal preparation. Consequently, it was found that cellulose, hemicellulose, and pectin-like constituents in the crop residues could be successfully integrated into nanocrystal and nanofiber formation. However, it has been highlighted the importance of replacing hazardous reagents and acidic treatments with eco-friendly reagents and technologies. Hence, it is important to have further studies in this regard. Furthermore, it has also been identified the importance of paving the attention towards the green extraction technologies over conventional solvent extraction technologies in phytochemical extraction from agricultural wastes as a means of reducing excessive amounts of organic solvents, energy, and time (Moro et al., 2021). Accordingly, supercritical fluid extraction (SFE), microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), and pulsed electric field (PEF), etc. have been identified as eco-friendly greener extraction approaches that could be successfully incorporated into phytochemical extraction (Chemat et al., 2019). Therefore, to utilize agricultural wastes for phytochemical extraction as a sustainable move towards enhancing food security and environmental sustainability, further research should be conducted for optimizing green extraction technologies for different agricultural waste constituents (Dahmoune et al., 2015).

Furthermore, researchers have conducted numerous research on using agricultural waste as an adsorbent in wastewater treatment. Rice husk, sugarcane bagasse, sawdust, coconut husk, oil palm-like agricultural waste materials can be used as a low-cost adsorbent in the treatment of wastewater (Mohammed et al, 2014). Accordingly, Khan et al., (2004) present that the above adsorbents show a high degree of heavy metal removal efficiency for heavy metals such as chromium, nickel, lead, copper, mercury, zinc, and cadmium. Therefore, it is important to focus more on the examination of agricultural waste as an adsorbent in wastewater treatment and improving this technology for sustainable utilization of agricultural waste.

Additionally, Agricultural waste can be used for the innovation of low-cost and environmentally friendly construction materials (Madurwar et al., 2013). Development of rice husk ash-based sand-cement block (Lertsatitthanakorn et al.,2009) and development of a Binder-less Cotton Stalk Fiberboard (BCSF) made from the cotton stalk (Zhou et al., 2010) are two instances which research have been conducted for innovation of construction material from agricultural waste. Accordingly, research should be conducted by manufacturers to develop innovative construction materials.

Moreover, the lack of knowledge among the general public on smart-farming and other novel strategies and technologies that is potential to integrate for sustainable agricultural waste management is another challenging issue that needs to be addressed. Hence, more research should be focused on the formulation of a new generation of agricultural system data, models, and knowledge products considering more on user needs to accelerate towards food security and sustainable development challenges (Antle et al., 2017).

## 4. Conclusion

Conversion of waste to energy, food, and animal feed production, composting are the most common conventional technologies that are in practice for sustainably utilizing agricultural wastes.

Bioremediation, biofertilizer production, and smart waste management technologies were the recently emerged effective technologies for sustainably utilizing agricultural wastes. However, further research needs to conduct on these approaches to maximize their potential benefits more towards sustainability.

Novel and sophisticated techniques for expanding the alternative uses of agricultural waste have been developed based on industrial innovation and high technology. However, future research focus on the optimization of these techniques based on the composition of different agricultural wastes are of immense importance. Moreover, the formation of a new generation of agricultural system data, models, and knowledge products should be a high focus in the future to guarantee resource efficiency, food security, and environmental sustainability through the effective utilization of agricultural wastes.

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