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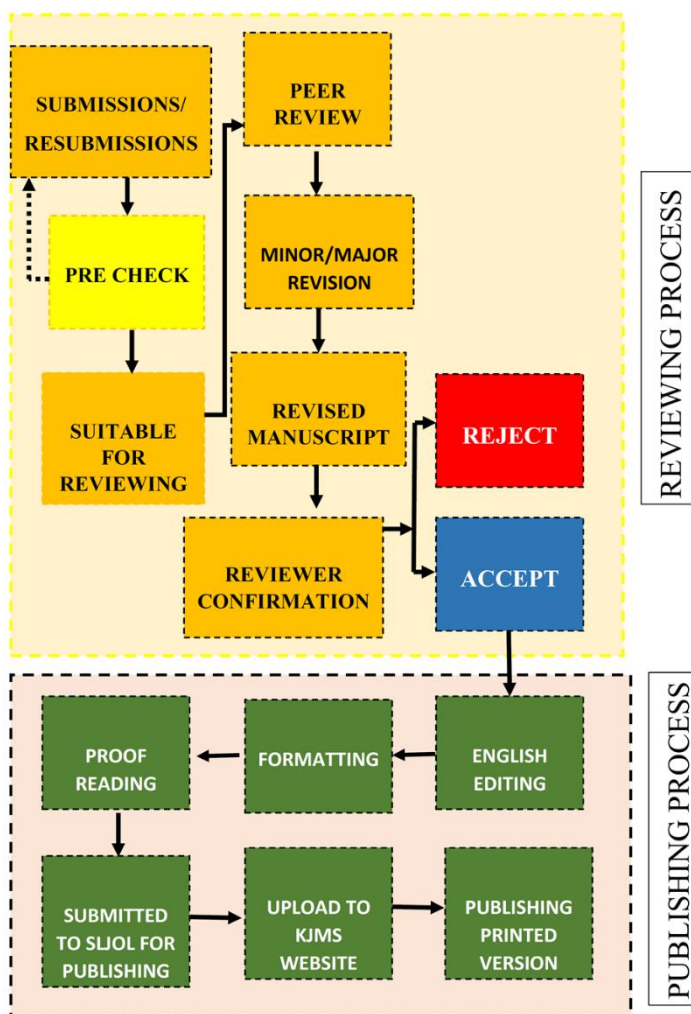
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A SYSTEMATIC CHARACTERIZATION OF STRUCTURAL BRAIN CHANGES IN EPILEPSY USING MAGNETIC RESONANCE IMAGING

Daswatte MRAU¹, Grero P.R.¹, David A.A.¹, Jayarathne R.E.P.¹, Pallewatte A.S.², Ediri Arachchi W.M.¹

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ABSTRACT

Grey matter and white matter changes in epilepsy detected by Voxel-based morphometry (VBM) and Tensor-based morphometry (TBM) show notable similarities and differences to date. Therefore, a direct comparison of results using VBM and TBM is necessary to understand how different methods are sensitive in detecting structural brain changes in epilepsy. 45 patients with epilepsy (27.62 ±12.8 years old) and 46 healthy controls (34.25 ±16.0 years old) were scanned using a 3 Tesla MRI scanner. T1 weighted brain images were acquired, pre-processed, and further analyzed using Computational Anatomy Toolbox (CAT12). For VBM, voxel-wise grey matter volumes, white matter volumes and cerebrospinal fluid volumes were computed and smoothed (Full width at half maximum, FWHM= 8 mm) for each participant. For TBM, voxel-wise Jacobian determinant images were obtained and smoothed (FWHM= 8 mm). The group differences between patients and healthy controls were obtained using two-sample T-tests. Conjunction analyses were performed to explore the sensitivity of different methods in detecting grey matter and white matter. Our results showed that although both methods detected widespread structural changes, there are similarities and differences in grey matter and white matter findings detected by different methods. Only 35.07 % of grey matter (cerebellum, right temporal gyrus, left cuneus and left superior frontal) were commonly detected by VBM and TBM while only 26.08 % of white matter (anterior lobe of cerebellum, left occipital, frontal, and right temporal regions) were commonly detected by VBM and TBM. Therefore, we conclude that VBM and TBM are differently sensitive in detecting structural brain changes in epilepsy.

KEYWORDS: *Epilepsy, Grey matter, White matter, Voxel based morphometry, Tensor based morphometry*

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1. INTRODUCTION

Epilepsy is identified as a neurological disorder that leads to altered brain activity, causing seizures, sensations, and loss of consciousness. Around 50 million people from the world population suffer from epilepsy, and it has become one of the most common neurological diseases globally and 80% of epilepsy patients are reported in low and middle-developing countries. It seems that this neurological condition is leading to a significant effect on patients' health as well as their wellbeing (Goldenberg, 2010, Sidhu et al., 2018).

Based on current evidence, neuroimaging scientists believe that structural and functional alterations in the brain may cause cognitive and behavioural abnormalities in patients with epilepsy. Many efforts have been made during the last few decades to map the structural and functional brain changes in epilepsy. More importantly, magnetic resonance imaging (MRI) based computational anatomy and imaging has received significant attention in searching the neuroanatomical substrates of epilepsy (Sidhu et al., 2018, Kini et al., 2016). Two methods, Voxel based morphometry (VBM) (Yasuda et al., 2010, Bernasconi et al., 2004) and Tensor based morphometry (TBM) (Tosun et al., 2011) have been extensively used to extract voxel level morphological information of the epileptic brain.

VBM is a fully automated technique in which spatially normalize the individual brains to a standard template and segment the different tissue types and then compute voxel-wise concentrations or volumes as GM, WM, and CSF (Ashburner and Friston, 2000, Beal et al., 2013). TBM characterizes voxel-wise gross volume changes following the deformation fields which are derived by normalizing the individual brains to a standard template. Further, it is a methodological alternative to detect gross volume changes of brain without computing volume information separately for different tissue types (Ashburner et al., 1998). The above two methods have been used to detect brain changes in epilepsy and they are evidenced with certain changes in focal and whole brain changes associated with epilepsy. Notably, apart from overall grey matter volume reduction of the entire brain, GM

volume reductions in hippocampal region and thalamus has been suggested for underlying hallmark symptoms of epilepsy. In addition, there may be more extensive sclerosis in surrounding structures like amygdala and para-hippocampal gyrus (Malmgren and Thom, 2012). Reports of juvenile myoclonic epilepsy confirm thalamus and frontal cortex as mostly affected areas by its condition (Kim et al., 2007). Furthermore, literature confirms that above GM changes are not existing alone and may be associated with many WM changes including inferior longitudinal fasciculus, and superior longitudinal fasciculus, corpus callosum and uncinate fasciculus (Xu et al., 2018). Regional gross volumetric deficits in the hippocampus have also been well documented in many TBM studies (Kim et al., 2011, Kim et al., 2013).

The results found to date using VBM and TBM in epilepsy show many similarities and differences. In such ground, we believe that some areas of the epileptic brain are affected more intensively and therefore the tendency to detect such changes by both methods are highly possible whereas some other areas are affected in a specific way and may be detected by either method. Therefore, a systematic and direct comparison of the structural changes in epilepsy based on VBM and TBM is required to test the above hypothesis, which would enable an understanding how different methods are sensitive in detecting structural brain changes in epilepsy. However, such systematic studies are very rare.

2. METHODOLOGY

Subjects

46 healthy controls (8 females; 34.25 ± 16.0 years old) and 45 epilepsy patients (8 females; 27.62 ± 12.8 years old) were included in the study. The study was approved by the ethical review committees of National Hospital of Sri Lanka and Faculty of Medicine, General Sir John Kotelawala Defence University. MRI brain scans which were confirmed as generalized epilepsy were selected from the imaging database of Department of Radiology, National Hospital of Sri Lanka. The patients had been first diagnosed by neurologists using diagnostic manual published by International League Against Epilepsy (ILAE) by the evaluations including patient history,

electroencephalography (EEG) recordings and neuropathological examination. Healthy participants with the absence of any neurological or psychological illnesses were also included in the study.

Magnetic resonance image acquisition

All participants underwent brain MRI scans that were performed using a 3 Tesla scanner (Philips Ingenia 3T) and 3D, T1-weighted images were acquired: echo time (TE) = 3.1 ms; inversion time (TI) = 900 ms; flip angle (FA) = 80; repetition time (TR) = 2200 ms; matrix = 256 x 256; slice thickness = 1 mm; field of view (FOV) = 226 mm x 290 mm; no gap; 188 sagittal slices.

Image preprocessing

The orientation of three-dimensional T1W images was checked for same orientation as the priors of SPM 12 (12th version of Statistical Parametric Mapping). They were pre-processed (bias-corrected, noise removed, intensity normalized) using the CAT12 (Computational Anatomy Toolbox- a powerful suite of tools for morphometric analyses with an intuitive graphical user interface) (Christian et al., 2022) and SPM12 toolboxes. Then, the pre-processed images were subjected to undergoing VBM and TBM analyses using CAT12 toolbox.

Voxel Based Morphometry

For VBM, pre-processed images were spatially normalized (this step is essential prior to performing statistical analysis) to MNI (Montreal Neurological Institute) template and then each brain was segmented into GM, WM, and CSF tissue classes using segmentation module of CAT12. Spatially registered data were displayed as single slices of each participant to check the quality of images and to detect possible native volume artifacts. In addition, sample homogeneity was also checked. We did not detect any images as outliers and none of them were removed. The segmented images were modulated to preserve the total amount of GM, WM, or CSF in the original image. This procedure resulted in volume images of GM, WM, and CSF respectively. Each volume image of participant was spatially smoothed using an isotropic Gaussian kernel with 8-mm full-width at half-maximum (FWHM). The total intracranial

volume (TIV) of each brain was used in the model of subsequent statistical analysis to remove the inter-individual differences to produce relative volumes rather than absolute volumes.

Tensor Based Morphometry

For TBM, voxel-wise Jacobian determinants (measuring the changes in regional tissue volumes using the deformation field derived from warping the MNI template to each individual brain) were obtained and smoothed (FWHM = 8 mm). This TBM process did not involve tissue segmentation rather it was matched with the anatomical correspondence in between the reference template and each image. Voxel level volume changes and positional displacements were originally recorded in deformation fields derived by spatial matching. Then the local Jacobian determinants were derived to quantify the local volume changes for each voxel. Finally, the Jacobian determinant values greater than one were taken as volume enlargement, whereas Jacobian determinant values less than one were taken as volume reduction (Gaser et al., 1999).

Univariate Statistical Comparison

We conducted Two-sample t test to find out group differences between patients with epilepsy and healthy controls using the statistical module available in CAT12. We used VBM-GM volumes, VBM-WM volumes, VBM-CSF volumes and TBM gross volumes separately at each statistical test comparison. In this analysis, we used age and gender as covariates in the model. For VBM, TIV was used as an additional covariate (TIV was quantified using ‘Get TIV’ module of cat12). It should be noted that TIV should not be taken as an additional covariate for TBM because inter-individual differences of brains are originally removed when deriving the deformation fields. The corrected results for family-wise error (FWE) at voxel level ($p < 0.05$) were presented.

Conjunction analysis

Further, conjunction analyses were performed between GM volume changes detected by VBM and TBM and between WM volume changes detected by VBM and TBM separately. We used grey matter and white matter masks to extract grey matter and white matter

information from gross volume changes detected by TBM (Ediri Arachchi et al., 2020). Image processing steps are shown in Figure 1.

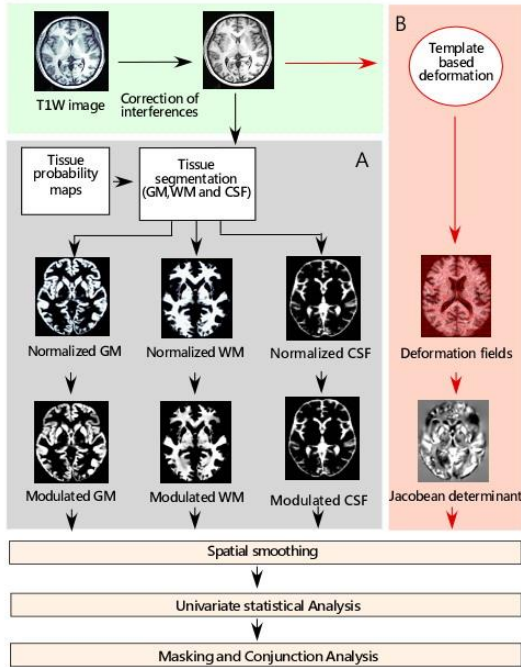


Figure 1: Image-processing workflow of Voxel-based morphometry (VBM; grey in A) and Tensor-based morphometry (TBM; red in B). GM, grey matter; WM, white matter; CSF, cerebrospinal fluid.

3. RESULTS

Univariate statistical comparisons

We found widespread volume reductions (Grey matter, white matter, and gross tissue) in epileptic brains compared to healthy controls covering both hemispheres. The results are shown in Figure 2 and summarized in tables 1 and 2. Compared with VBM, TBM was more sensitive and was able to detect more anatomical changes in the epileptic brain, more specifically the white matter, compared with VBM derived white matter.

The gross volume reductions were observed in the regions of cerebellum, cuneus, middle occipital, superior occipital, precuneus, lingual, middle temporal, superior temporal, inferior temporal and

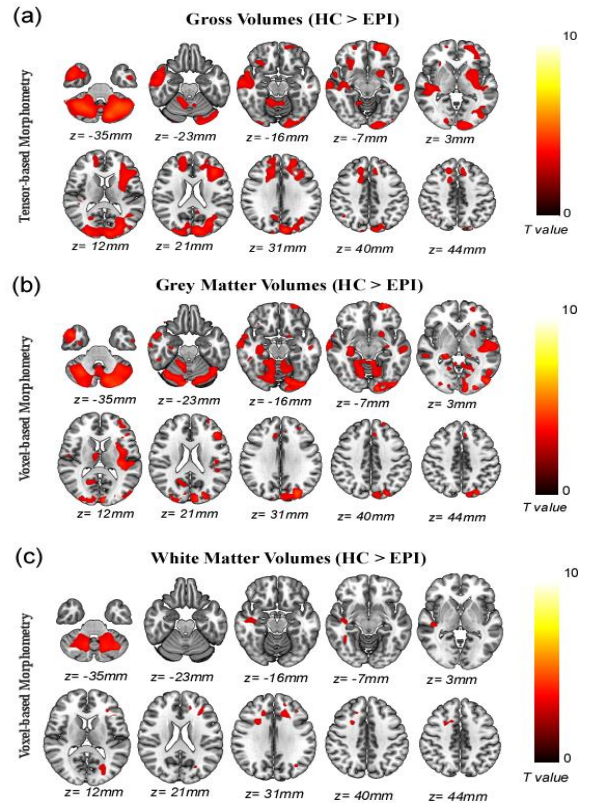


Figure 2: Regional gross volume abnormalities in patients with epilepsy compared to healthy controls detected by Tensor-based morphometry (panel a). Regional grey matter volumes (panel b) and white matter volumes (panel c) detected by Voxel-based morphometry. All detected areas, indicated in black to white (corresponding to T values obtained from two-sample t tests), had reduced volumes in patients with epilepsy compared with healthy controls. ($p < 0.05$, FWE Corrected).

inferior frontal. In addition, unilateral GM reductions were found in left superior frontal, right fusiform, right hippocampus, right superior parietal, right inferior occipital, left postcentral, left thalamus, right medial frontal, and right cingulate, left middle frontal, left putamen and left insula. The main white matter contribution was reported from cerebellum. In addition, extra nuclear, sub lobar and sub gyral white matter were highlighted from frontal and temporal lobes (Figure 2 a).

VBM has demonstrated several GM impairments in the epilepsy group in comparison to healthy controls. Bilateral grey matter volume reductions were found in cerebellum, middle occipital, middle temporal gyrus and superior occipital, cuneus and parahippocampus. In addition, unilateral GM reductions were found in right fusiform, left insula, right hippocampus, right thalamus and left superior frontal (Figure 2 b). Apart from GM findings, this study was also able to distinguish white matter volume reductions in anterior and posterior lobes of cerebellum. Compared to cerebellum, slight WM reductions were noted in sub gyral regions of frontal, left occipital, right temporal, and left occipital (Figure 2 c). It should be noted that we did not detect CSF changes in TBM or VBM.

Table 1: Regional gross volume reductions detected by tensor-based morphometry (TBM) in patients with epilepsy compared to healthy controls.

Cluster No.	Atlas region	Peak MNI Coordinates	t Value	Cluster size (Voxels)
Gross Volume changes				
1	Cerebellum, cuneus, middle occipital, superior occipital, precuneus, lingual, cerebellar white matter	-31.5, -60, -37.5	5.25	44790
2	Left superior frontal, left middle frontal, left putamen, left insula, left inferior frontal, left middle temporal, left superior temporal, sub lobar and sub gyral white matter	-37.5, 30, 22.5	4.53	15537
3	Right middle temporal, right superior temporal, right inferior temporal, right fusiform, extra nuclear, right hippocampus	46.5, 3, -33	4.45	9714
4	Right superior frontal, right medial frontal, right cingulate, sub gyral white matter	15, 28.5, 31.5	3.93	5791
5	Right inferior frontal, sub lobar white matter, extra nuclear white matter,	27, 27, -12	3.53	969
6	Right superior parietal	21, -63, 66	4.24	762
7	Left inferior temporal	-49.5, -3, -31.5	3.43	274
8	Right inferior occipital	27, -91.5, -19.5	3.50	254

Statistical significance was thresholded at $p < 0.05$, FWE Corrected. Atlas regions were defined based on the AAL atlas. Age and gender were used as covariates. MNI, Montreal Neurological Institute; L, left; R, right.

Similarities and Differences in GM changes detected by different methods

Conjunction analysis revealed a considerable overlap (35.07%) in the identified GM structural changes in patients with epilepsy across VBM and TBM methods. This overlap includes several regions such as cerebellum, right temporal gyrus, left cuneus and left superior frontal gyrus (Figure 3 a, brown areas).

Table 2: Regional grey matter (GM) and white matter (WM) volume reductions detected by voxel-based morphometry (VBM) in patients with epilepsy compared to healthy controls.

Cluster No.	Atlas region	Peak MNI Coordinates	t Value	Cluster size (Voxels)
GM Volume changes				
1	Cerebellum, left middle occipital, left superior occipital, Cuneus, left para hippocampus, Left middle temporal, right fusiform.	-9, -94.5, 7.5	5.76	28718
2	Left insula	-37.5, -21, 6	5.14	5274
3	Right middle temporal	45, 6, -36	4.69	2522
4	Right hippocampus, right para hippocampus	22.5, -33, 1.5	4.13	1215
5	Right middle occipital, right superior occipital, right cuneus	16.5, -96, 10.5	4.16	998
6	Left superior frontal	-27, 63, -12	4.25	471
7	Right thalamus	6, -7.5, 12	3.62	398
8	Right fusiform	28.5, -1.5, 43.5	3.92	295
9	Right middle temporal	54, -34.5, -4.5	4.02	225
WM Volume changes				
1	Left cerebellum posterior lobe, left cerebellum anterior lobe.	-37.5, -57, -37.5	4.58	2822
2	Right cerebellum posterior lobe, right cerebellum anterior lobe.	40.5, -51, -39	4.46	2426
3	Sub gyral (Left frontal)	-19.5, 48, 27	3.98	940

Statistical significance was thresholded at $p < 0.05$, FWE Corrected. Atlas regions were defined based on the AAL atlas. Age and gender were used as covariates. MNI, Montreal Neurological Institute; L, left; R, right.

Apart from overlaps some regional GM structural changes (27.03%) in volume space were only detected by VBM, but not by TBM (Figure 3 a, red areas). These areas include the left insula and right

cerebellum. Further, several GM volume reductions were only detected by TBM (37.88%), but not by VBM (Figure 3 a, green areas). These regions include the left putamen, middle occipital gyrus and superior frontal gyrus.

Similarities and Differences in WM changes detected by different methods.

We noticed considerable overlaps of WM results (26.08%) detected by VBM and TBM. Commonly detected white matter areas were mostly associated with anterior lobe of cerebellum, left occipital, frontal, and right temporal regions (Figure 3b, brown areas). Further, it should be noted that TBM alone has been able to detect several scattered white matter volume reductions (71.4%) covering frontal, occipital and temporal lobes of the cerebrum (Figure 3b, green areas). However, we did not find a significant amount of WM reduction detected by VBM alone (2.5%).

4. DISCUSSION

We used two popular methods (VBM and TBM) to characterize structural brain changes in epilepsy. The aim of the study was to investigate how different methods are sensitive in detecting structural brain changes in epilepsy. The main strengths of this study are two folds. First, comparing results from different studies does not allow direct comparisons between results obtained using different methods due to the use of different sample sizes, different stages of illness, changes in medication level of subjects and distinct data processing strategies applied in different studies. Second, although structural changes detected by these different methods are likely to be related to each other, they also capture information from different aspects and thus are likely to have different sensitivity in detecting different types of structural changes.

We observed two main findings with respect to each tissue type. First, regarding the structural changes, each tissue type is associated with wide-spread volume reductions in epilepsy, but a portion of these structural changes were commonly detected by both methods. Second, in addition to overlaps we detected, several regional volume reductions which are only specific to the structural method applied were also reported. For an example, significant amount of non-overlapping or method specific regions in grey matter were found by both TBM and VBM respectively. Further, TBM was able to detect large amounts of white matter regions which are independent from overlapping. Therefore, it is obvious that although structural changes detected by these different methods are likely to be related to each other, they also capture information from different aspects and thus are likely to have different sensitivity in detecting different types of structural changes.

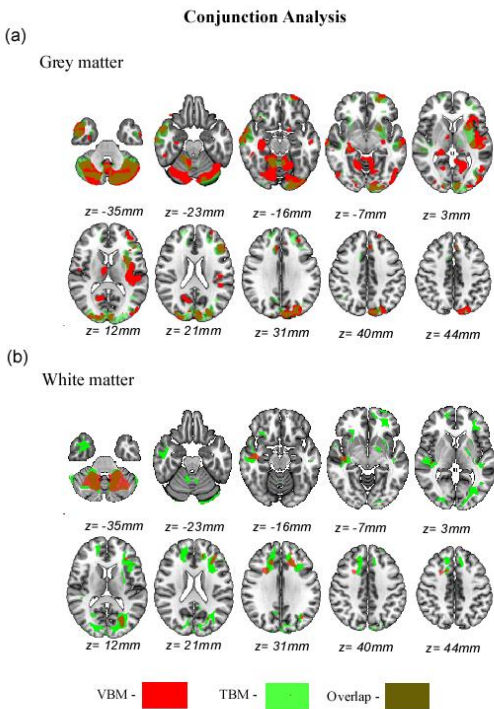


Figure 3: Conjunction analysis of grey matter detected by Voxel-based morphometry and Tensor-based morphometry (panel a) and white matter detected by Voxel-based morphometry and Tensor-based morphometry (panel b)

superior frontal) (Jobst et al., 2019, Lu et al., 2022). Amongst grey matter regions cerebellum was specifically noted by both methods. Although the cerebellum is not traditionally associated with epilepsy there is plenty of evidence to show that cerebellum plays a significant role in seizure networks (Streng and Krook-Magnuson, 2021, Ibdali et al., 2021). Reduced white matter volumes associated with cerebellum was mostly highlighted and scattered reductions were shown in frontal, occipital and temporal regions (Tae et al., 2010, Slinger et al., 2016). Deformation based studies conducted to date on epilepsy have revealed more pronounced tissue volume reductions in frontal parietal and temporal regions (Tosun et al., 2011). Among sub-cortical regions hippocampus have been the most featuring anatomical region in literature whereas we did not detect bilateral volume reductions in hippocampus with TBM, rather it was only confined to the right side (Kim et al., 2013).

GM findings detected by VBM have been considerably confirmed by gross volume changes detected by TBM. But VBM has failed to confirm or TBM has detected more white matter volume changes in epilepsy. In addition to GM and WM, we were interested in presenting possible CSF changes associated with epilepsy. However, we did not observe any significant changes in CSF. It is not surprising that the literature has hardly reported the involvement of CSF changes in epilepsy.

VBM approach applied in this study converts the original density value of the GM (or the WM) into the absolute volume of the given tissue type, and then removes the effects of global brain volume by regressing out the TIV during the statistical comparisons and obtained relative volumes at voxel level. The TBM approach applied in this study can restrict information on deformation fields to local volume changes, by using the local Jacobian determinant of the deformation matrix at each voxel. This can be seen as a shrinkage or enlargement of the volume. It is important to note that TBM does not distinguish different tissue types (GM, WM, and CSF) within a particular voxel, but it quantifies the gross volume changes at voxel level. As VBM and TBM are closely related, one may expect close relationships between the findings of grey matter and white matter.

For an example, one would expect that the gross volume reductions detected by TBM may indicate reduced GM volume, WM volumes and CSF volumes (measured by VBM). Because theoretically the gross volume of tissues comprises all three tissue types such as GM volumes, WM volumes and CSF volumes.

We believe that the similarities and differences found in the findings of the present study could be explained by methodological properties or their sensitivities to detect different structural information of brain. In principle, TBM follows the method of mapping each point of the template to corresponding point of the image based on displacement vector and Jacobean matrix. Therefore, the tendency of the occurrence of registration errors at TBM is more prone than at VBM. Therefore, we believe TBM contains more noise in comparison to VBM. Further, the possibility of the occurrence of errors would be much increased when the registration uncertainty is higher. Apart from that VBM is suggested as the more powerful method of detecting local anatomical changes in comparison to TBM (Davatzikos et al., 2001, Eckert et al., 2006, Ediri Arachchi et al., 2020b, Khan et al., 2015, Yushkevich et al., 2005, Borghammer et al., 2010). In summary, inherent methodological alterations of VBM and TBM could be directly related with the finding derived from them.

5. CONCLUSION

We conclude that although both methods detected widespread structural changes, there are similarities and differences in GM and WM findings. Therefore, we confirm that VBM and TBM are differently sensitive in detecting structural brain changes in epilepsy.

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THE NECESSITY OF LAWS ON THIRD-PARTY AND CIVIL LIABILITY FOR INDUSTRIAL NUCLEAR DAMAGES CAUSED BY INSTALLATIONS: HEALTH ASSURANCE COMPENSATION

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ABSTRACT

With the modern requisites of humankind, energy has become the most depleting resource due to waste and lack of sources. In the present world, nuclear energy sources play a vital role in producing energy by fueling radioactive elements. The most significant feature of atomic energy is that a small amount of radioactive substances can release a tremendous amount of energy. Most developed and developing countries use nuclear energy as a power-making resource for public and private purposes. Therefore, it is imperative that a developing country like Sri Lanka adopt nuclear power technologies and the laws governing nuclear operations. This research discusses international nuclear laws and the need for a legal framework to manage the liability of nuclear damages in terms of people's health and potential harm to health, past experiences of exposure to ionizing radiation are discussed with statistics to find out the necessity of laws on nuclear liability in terms of health compensation. The scrutiny supplies a directive authority to make domestic legislation without being dependent on international instruments, as the paper also discusses the drawbacks of international nuclear liability regimes against principles of nuclear law and the essentials of a nuclear liability regime. The primary objective of the study is to find out directive measures for a nuclear liability regime in terms of health assurance. In addition, this research also discusses directive principles to make equitable compensation liability schemes from the victims' perspective. The books, research papers, international conventions, and domestic legislation were the primary sources of the research. Sri Lanka's legal framework needs improvement as an independent law, aligning with the Vienna Convention on nuclear liability, as international law lacks equitable aspects.

KEYWORDS: Nuclear Law, Ionizing Radiation, Nuclear Liability, Strict Liability, International Law

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1. INTRODUCTION

All humanity is from an ancient civilization, and even before that, they needed power to continue their lives. During the initial period, humans could not be provided with power. Nevertheless, after the discovery of fire, humankind gradually developed different power sources.

The idea of nuclear power began in 1930 after the discovery of the scientist Enrico Fermi, the ability of neutrons to split atoms. With that great discovery, of nuclear power came into discussion and there was a great interest from the scientists on that. Enrico Fermi, with a team at the University of Chicago, could make the first chain reaction. Fermi's test was possibly not the first chain reaction. It was the first time scientists could make it happen in a lab by themselves. They could understand that the atoms can release the energy stored in the center of the atom, generally called the nucleus, by splitting. This process called "nuclear fusion," converts the stored energy to the energy of heat, correspondingly there emerges the energy conservation law. As the next step, the produced heat is directed to a cooling agent, and after a process of a turbine (which is not mentioned here), the process makes electricity. It is vital to understand that only the atoms of radioactive elements can be used as splitting ones. For example, Uranium, Palladium, and Polonium are radioactive elements used in power generation.

Radiation exposure can result in three different forms: natural, planned, or accidental. Since this paper aims to determine the third-party liability of transportation of radioactive substances and nuclear installations, it discusses about accidental radiation exposure.

1.1 What are Nuclear Damages?

The term "Nuclear damages" has been defined in the Vienna Convention on Nuclear Liability as "loss of life, any personal injury or any loss of, or damage to, a property which arises out of or results from the radioactive properties or a combination of radioactive properties with toxic, explosive or other hazardous properties of nuclear fuel or radioactive products or waste in, or of nuclear material coming from, originating in, or sent to a nuclear

installation; (ii) any other loss or damage so arising or resulting if and to the extent that the law of the competent court so provides; and (iii) if the law of the Installation State so provides, loss of life, any personal injury or any loss of, or damage to, a property which arises out of or results from other ionizing radiation emitted by any other source of radiation inside a nuclear installation".

1.2 What is civil and third-party liability?

In litigation, civil responsibility is a legal duty that forces a party to pay for damages or to execute other court-enforced orders. In contrast to criminal responsibility, which is frequently filed by the State to correct a public wrong, civil liability or third-party liability is typically brought out by a private person seeking damages, injunctions, or other remedies against financial and bodily injuries or losses caused by any act of a responsible party. Most of the time, the terms civil liability and third-party liability are used synonymously.

E.g.: In a vehicle accident, the wounded individual can sue the driver and seek monetary compensation. In a nuclear disaster, the responsible person or the organization has the liability towards victims, and victims seek financial compensation.

2. METHODOLOGY

The scrutiny is based on the information, data, and knowledge gathered primarily and secondarily from statutes, reports, books, journal articles, and online written materials. The methodology used was doctrinal as the research takes a comparative analysis while providing a directive measure for the legal framework Sri Lanka needs. The area of discussion completely depends on the existing legal framework and the ideal law that would fit the current needs. Nuclear laws are completely written and the gaps and problems had to be found in such materials. The paper discusses the legal framework of Sri Lanka comparatively with the international legal framework on nuclear liability. As the modern method of energy creation, the need for laws on the nuclear regime has been recognized all over the world. Therefore, in the paper, the Sri Lanka jurisdictions are compared with the international legal regime.

3. RESULTS AND DISCUSSION

Considering the law related to nuclear affairs in Sri Lanka, nuclear matters are currently governed by the Sri Lanka Atomic Energy Act No. 40 of 2014. Further, there was no legal framework to manage nuclear liability in case of a nuclear disaster. For that reason, this research took place to evaluate the necessity of a legal framework for health issues that can be raised and to find out how to compensate for those health complications that can result from ionizing radiation in the event of nuclear damage happening to a nuclear installation. As a specific feature, the research was conducted to find out directive measures to make fair legislation to compensate victims of nuclear damage in terms of health damages. Therefore, the paper focused even on the drawbacks of the current international legal framework on third-party and civil liability in nuclear damage. The lack of legislation on atomic liability led to the need for conducting the research for this paper, and the lack of literature on similar topics became a motivational factor and a disadvantage in conducting the research.

3.1 International Nuclear Law

Nuclear law is "The body of special legal norms created to regulate the conduct of legal or natural persons engaged in activities related to fissionable materials, ionizing radiation, and exposure to natural sources of radiation" (Stoiber, 2003b).

With the principal objective of "to accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world", the International Atomic Energy Agency (IAEA) established its statute on October 23 1956 at the United Nations headquarters, New York. The same entered into force on July 29, 1957. Nuclear law is "The body of special legal norms created to regulate the conduct of legal or natural persons engaged in activities related to fissionable materials, ionizing radiation, and exposure to natural sources of radiation" (Stoiber, 2003). According to IEAE, the objective of nuclear law has been construed under the context of liability for nuclear damages. With the participation of the UN, IEAE on this matter promoted implementation and adherence; to a set of agreements

and conventions on nuclear law. Such agreements and conventions which ensured the peaceful usage of nuclear power, are the Convention on Early Notification of a Nuclear Accident, the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, the Convention on Nuclear Safety, the Joint Convention on the Safety and Spent Fuel Management and the Safety of Radioactive Waste Management. All that respectively discharged the duty to immediate notification in a nuclear accident which was adopted in 1986. That was after the Chernobyl nuclear accident. The cooperation of state parties assisted in nuclear accidents, to ensure a high level of safety on land-based nuclear power plants, and the joint convention addressed the issues in spent fuel and radioactive waste management for the first time.

Convention on Early Notification of a Nuclear Accident established a system for notification in the event of nuclear damage as the primary objective. The Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency made a framework to assist immediately the victims in the event of a nuclear accident. The parties are bound to assist such victims regardless of the nationality of the victim. The state parties that subscribed the Convention on Nuclear Safety are bound to make safety measures in nuclear practice. The Joint Convention on the Safety and Spent Fuel Management and on the Safety of Radioactive Waste Management provides a framework to manage spent fuel in nuclear installations and the wastage of the installation. Participation of IEAE is appreciable in the internationally binding legal framework through treaties under the auspices of IEAE, agreements to which IEAE is a party, and IEAE-related treaties (*Treaties*, n.d.).

The treaties under IEAE auspices are the Agreement on the Privileges and Immunities of the IAEA, which was established on the 1st of July 1959, and it contains provisions for the settlement of disputes, use of laissez-passer, abuses of privileges, immunity and privileges of officials, representations of members, facilities in respect of communications, property, funds, and assets of the agency and juridical

personality of the agency. In addition to the treaties mentioned in the previous paragraph, Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, Convention on the Physical Protection of Nuclear Material, Amendment to the Convention on the Physical Protection of Nuclear Material, 1963 Vienna Convention on Civil Liability for Nuclear Damage contains provisions on civil liability of nuclear damages. That aim to ensure compensation for damages caused by nuclear installations and transportation, the optional protocol to Vienna convention, protocol to amend Vienna convention, Joint Protocol Relating to the Application of the Vienna Convention, and the Paris Convention and Convention on Supplementary Compensation for Nuclear Damages. The Joint Protocol ensures that only one of the two conventions applies to any given nuclear incident and that both the liable operator and the amount of its liability are determined by the convention to which the State whose territory the liable operator's installation is located is a party. The Joint Protocol applies not only to the original Paris and Vienna agreements; it applies also to any changes to either convention that is in effect for a party to the Joint Protocol.

There are eleven (11) fundamental principles of international nuclear law, i.e. the safety principle, the security principle, the responsibility principle, the permission principle, the continuous control principle, the international cooperation principle, the transparency principle, the independence principle, the sustainable development principle, the compliance principle, and the compensation principle (Stoiber, 2003).

Safety is the predominant principle as the standard and primary requisite of using nuclear energy – the safety of the operators and third parties. Therefore, the laws imposed regarding nuclear operations shall be stringent, and they ensure the protection and safety of the general public from nuclear accidents and ionizing radiation which harm the health of the general public.

Considering the Security principle, most nuclear operations commenced with the national security and military activities of several powers such as the United

States of America and the Union of Soviet Socialist Republics (present Russia). The laws shall be imposed under this particular principle to ensure the security of the people from accidental and intentional diversions from legitimate usage of nuclear materials. Simply, in military invasions and in terrorist attacks, the radioactive sources may be captured by opponent military regimes and may use the seeds in illegitimate and risky methods. This principle emphasizes making international, national, and subnational laws to prevent the unlawful use of radioactive sources and abandoned nuclear installations. In contrast, in the Russian invasion of Ukraine, both parties tended to attack atomic facilities and sources irrespective of the loss of security of persons from ionizing radiations. Correspondingly, regarding the security principle, IEAE has implemented several treaties on nuclear weapon usage. The "Law of Space" even emphasizes on non-establishment of nuclear weapons in the atmosphere or space.

Various governmental and non-governmental agencies use Responsibility Principle needs, Nuclear power and radioactive materials for scientific purposes, medical purposes, power generation, construction, etc. The problem arises as to how the responsible party in the event of an accident of nuclear installation or transportation can be determined. International nuclear law has identified and sorted out the problem by making the operator or/and the licensee the responsible person. This responsibility is a strict liability where the *mens rea* (offensive intention) is not accountable. According to the Vienna Convention on Nuclear Liability, the operator "concerning a nuclear installation, means the person designated or recognized by the Installation State as the installation operator". The liability acts are laid down in Article 2 of the Vienna Convention. Article 4 (1) of the same convention has established the rule of absolute/strict liability of the operator. Article 4(3) states the instances in which the operator is free from liability which should be covered under the security principle.

The permission principle says that nuclear operations shall obtain prior authorization from the regulatory bodies engaged in the process due to the risks involved. This principle is fundamental as the regulator can revoke authority whenever they realize

such radioactive materials' excessive, illegitimate, and unsafe use. The power given for such nuclear operations must be inspected, monitored, and regulated continuously to protect the most predominant fundamental principle of nuclear law, the safety principle. The regulator shall examine from time to time the adherence to the regulatory framework.

As per the Compensation Principle, Nuclear energy has the potential to do significant harm to people, property, and the environment, depending on a variety of technical considerations. Because preventative measures cannot eliminate the possibility of such injury, States are required under nuclear legislation to take precautions to offer sufficient compensation in the case of a nuclear disaster. The compensation regimes in international law are stated in Vienna and Paris Conventions.

The underlying idea is that economic and social progress can only be sustainable if the world's environment is safeguarded from destruction. It is instrumental in the nuclear sector since some fissile materials and sources of ionizing radiation can pose long-term health, safety, and environmental problems. It is instrumental in the nuclear industry since some fissile materials and sources of ionizing radiation can pose long-term health, safety, and environmental issues. Because of the extremely long lifespan of these materials, it is impossible to identify which present steps are required to sufficiently protect future generations in the very distant and unexpected future. One approach to applying the principle of sustainable development in the nuclear field has been to urge that the current generation do everything possible to ensure long-term safety, without limiting options for future generations or relying too heavily on long-term forecasts, which are unlikely to be accurate over the long timescales involved.

In monist states, the State is bound by international law without specific legislation passed by the local legislature, while in dualist countries, it needs to pass particular laws after the ratification of international treaties. However, whether the State ratified the treaties on liability, following international customary law, a state in which occurred nuclear accident is

liable for the damages caused to other states due to the radioactive contaminations. When making national/ domestic laws, it should also comply with this principle to ensure international or customary law conformity.

It is sufficient to emphasize at this point that nuclear legislation lays particular emphasis on forming a regulatory authority, the judgments of which on safety problems are not subject to influence by businesses involved in developing or marketing nuclear energy. Given the enormous hazards inherent in nuclear technology, other interests must submit to the regulator's independent and professional judgment regarding safety.

The usage of nuclear energy commenced in military operations in World War 2. Therefore, the parties were in danger of leaked information about such a nuclear regime. The flourished nuclear law required transparency in nuclear operations to promote the peaceful use of nuclear energy. The government's responsibilities shall have utmost good faith in supplying accurate and relevant information to ensure the general public's safety from nuclear accidents and ionizing radiation harms.

Finally, as per the International Cooperation Principle, users of nuclear methods and regulators of nuclear activities must maintain strong contacts with colleagues in other countries and appropriate international organizations. Several variables influence the international dimension of nuclear energy. First, in the area of safety and the environment, the potential for transboundary impacts necessitates governments harmonizing policies and developing collaborative programmes to reduce the risks of damage to their citizens and territories, the global population, and the planet as a whole. Lessons learned in one State about enhancing safety can be highly relevant to improving the situation in other States. It is vital to improve the safety of nuclear activities and facilities worldwide that such lessons be promptly and widely shared. The use of nuclear material poses security dangers that transcend national boundaries. Terrorist risks, as well as concerns linked with illegal nuclear material trafficking and nuclear explosive proliferation, have long been recognized as

issues needing a high degree of international cooperation. Various international legal instruments have been enacted to codify states' duties in the nuclear area. Governments must comply with such responsibilities in good faith, and the wording of those instruments may limit lawmakers' authority in formulating national legislation on specific issues they cover. Fourth, the increasingly global nature of the nuclear sector, with frequent transfers of nuclear material and equipment across national boundaries, necessitates parallel and collaborative methods by both public and private organizations for adequate control. For these reasons, national nuclear energy law should include suitable provisions to encourage public and commercial nuclear energy users to engage in important international nuclear activities.

3.2 Drawbacks of International Legal Instruments

The 1963 Vienna Convention, which followed the Paris Convention on Civil Liability of 1960, unlike the Paris Convention, has broadly defined the term "Nuclear Damages," which was again defined more broadly by the 1997 Vienna Protocol. The liability of the nuclear operator is absolute with several exemptions like armed conflicts, civil uprisings, and grave natural disasters, which are subjected to the domestic law of the state party. Still, the maximum financial security needed from the nuclear operator is as low as 5 million USD. The Vienna Protocol again broadened the definition of nuclear damages, extending the claim period. The limit of liability brought up to 300 million SDR. Article 4 of the Paris Convention says the operator of the insurance company shall take the whole liability between 5-15 million USD. The exception in the Vienna Convention applies similarly to the Paris Convention. Both the Vienna and Paris Conventions say the jurisdiction of such nuclear damage lies on the State that the nuclear installation states. Notably, legislation on nuclear liability should not limit the liability amounts as a legislator or an international body cannot decide the value of a person's health and their lives, which should be an essential principle when drafting a nuclear liability regime.

The Vienna Convention does not define economic and environmental loss regarding nuclear damages. People may suffer health disadvantages directly and indirectly from ecological and financial losses, and on the other hand, economic and environmental loss could arise from health issues and deaths. Vienna Protocol has introduced environmental reinstatement under nuclear damages. Unfortunately, it is silent on compensation where the reinstatement is impractical. By comparing nuclear conventions with the European Directive of Liability, Directive 2004/35/EC requires operators to take restorative and preventive measures to safeguard the environment, which can harm human health where damage has already occurred. This requirement is also extended for imminent threats of such damage (Sands & Galizzi, 2010).

Vienna Protocol defines nuclear damages as "loss of income deriving from an economic interest in any use or enjoyment of the environment, incurred as a result of a significant impairment of that environment, and insofar as not included in subparagraph (ii)". It is crucial to note that the term 'significant' is not defined properly. Operators are likely to argue that there is always a certain level of radiation. Therefore, the definition should be amended to define the term 'significant' unambiguously. The Revised Vienna and Paris Conventions established provisions to confer exclusive jurisdiction to the State where the incident occurred. This complies with the legislative measures which must be adhered to in making nuclear liability laws. The Vienna Convention has imposed a ten-year period to claim nuclear damages, which is not an adequate period of time at all. As discussed in the previous topic, health issues may arise even after ten years, especially genetic disorders and cancers. Therefore, as mentioned in the Vienna Protocol, the legislature should focus on extending the period to at least 30 years.

3.3 International Instruments on Civil and Third-Party Liability

There are two main conventions regarding international civil and third-party liability instruments, i.e. the Vienna Convention and the Paris Convention. The principles settled by the International

Commission of Jurists (ICJ) required to establish environmental law in an international aspect and be liable for the ecological harm made transboundary. In the incident of the Chernobyl nuclear accident (1986), since the Union of Soviet Socialist Republics (USSR) had not ratified the Vienna Convention or Paris Convention, it was not subjected to ICJ, and due to its power exercised in the United Nations, the USSR did not compensate for the nuclear accident. After the incident, because of the non-reliable manner. Under these circumstances, the two conventions the two conventions were adjoined together by the Joint Protocol of 1988 by negating the bars to the parties to accept both conventions together. Previously, Western European countries only could become parties for the Paris Convention which was operated as a regional instrument while the Vienna Convention was a universal instrument. The parties to the Joint Protocol are bound by the Vienna Convention and the Paris Convention at the same time. The Brussels Supplementary Convention enhanced the scope of the Paris Convention. No state can become a party only to the Brussels Supplementary Convention without being a party to the Paris Convention (Bellamy, 2018).

Accordingly, eight international instruments on civil and third-party liability for nuclear damages exist. Those are the 1960 Paris, the 1963 Brussels Supplementary Convention, the 2004 Paris Convention (Protocol to 1960 one), the 2004 Brussels Supplementary Convention (protocol to 1963 one), the 1963 Vienna Convention on Civil Liability for Nuclear Damages, the 1997 Vienna Convention (protocol to amend 1963 one), 1997 Convention on Supplementary Compensation for Nuclear Damage, and 1988 Joint Protocol.

The Paris Convention is equipped with several Principles on third-party liability in the event of nuclear damages. Correspondingly, the operator of the nuclear installation will be liable for the damage caused by the facility itself and in the transportation of such radioactive substances that are needed for the nuclear installation. This liability is "strict" which means, the liability is on the operator, regardless of the intention. Therefore, the regulatory body needs the operator to submit security before commencing the operation in the nuclear installation. In addition, the

Paris Convention established a compensation scheme for injury, death, environmental pollution, economic losses, and some degrees of loss of income due to the nuclear accident.

3.4 Health and Safety Risks of exposure to radiation

As a comprehensive definition as affirmed by the Agency for Toxic Substances and Disease Registry, "Radionuclides (or radioactive materials) are a type of chemical in which the nucleus of an atom is unstable (*Radionuclides* | US EPA, 2023). They accomplish stability By modifying the nucleus that can be referred. For example, Cesium, Cobalt, Iodine, Plutonium, Radium, Radon, Strontium, Thorium, Uranium, etc. can be referred. There are 38 radioactive elements, of which Uranium is widely used in nuclear power plants worldwide. In the context of transportation, "radioactive materials" are defined as any material with specific activity greater than 0.002 microcuries per gram. (United States Nuclear Regulatory Commission [USNRC, Reactor Concepts Manual], n.d.).

The effects of nuclear radiation can cause short and long-term diseases. Radiation sickness called Acute Radiation Syndrome (ARS) and skin injuries caused by radiation effects called Cutaneous Radiation Injury (CRI) are short-term effects. Long-term effects of radiation exposure are cancers, prenatal exposure, and mental distress can be resulted. (World Health Organization: WHO, 2023)

Excessive radiation exposure may damage living human cells and other organs that help the body function by affecting the genetic material called Deoxyribose Nucleic Acid (DNA). This exposure can make cancerous cells and tissues in the human body. A higher exposure dose or a higher exposure period to low radiation will harm the human body. The harm depends on several facts. Those are the type of radiation, the sensitivity of body cells, duration of exposure, the isotope, and individual characteristics of the person (*Radiation and Health*, 2023).

We saw in the Chernobyl accident that the damage caused by ionizing radiation was not limited to subjective territory. The damages extended far beyond regions as well to an extreme magnitude. Nuclear damage can mainly arise in nuclear power plant accidents, radioactive elements, and spent fuel transportation. However, the damages caused by radioactive waste are at a shallow level (*What Is Nuclear Waste and What Do We Do with It? - World Nuclear Association*, n.d.-b). Therefore, we should focus on discussing the damages that can occur in nuclear installations.

In the incident of Chernobyl, from 1986 to 2005, approximately 5 Million people were found around the contaminated area, which contained an accumulated whole-body average dose of 0.01 Gy ("Cancer Consequences of the Chernobyl Accident: 20 Years On," n.d.). In addition, researchers found an increased number of thyroid cancers and had shown the risk likely to cause cancers in the thyroid gland due to exposure to I-131 (Brenner AV, Mykola DT, Hatch M, n.d.[2011])

The radioactive isotopes released in nuclear installation accidents include Iodine-131, Cesium-134, and 137 (Cs). Also, Plutonium-239 and Strontium-90 (Sr) may be released in extreme-level accidents such as the Chernobyl nuclear accident in 1986 in Ukraine and Fukushima Incident. Iodine-131 generally affects humans via contaminated water, milk, or food items (World Health Organization: WHO, 2023). In addition, the I-131 contained dust is another way of affecting humans. I-131 can be cancerous to the Thyroid gland as the thyroid cannot distinguish non-radioactive Iodine and I-131, which is a radioactive isotope of Iodine. Cesium-134 and 137 also are fatal in terms of external and internal. External exposure to Sc-131 and 137 comes from touching the contaminated materials and walking on contaminated soil. Internal exposure can occur from breathing the dust contained with Cesium particles. In 2021, it was found that thyroid tumors in children exposed to Chernobyl nuclear accident have more DNA damage than in children born nine months after the accident (Morton LM, Karyadi DM, Stewart C, cn.d.[2021]).

The Fukushima nuclear accident in 2011 due to earthquakes followed by a tsunami made 4% of females exposed to contamination as infants, all solid cancer patients. Around 6% of females exposed as infants have breast cancer. 7% of males exposed to contamination as infants became leukemia patients. Unfortunately, 70% of females exposed as infants became thyroid cancer patients (Prentice, 2013).

3.5 Current Sri Lankan Legal Framework on Nuclear Relations

In the first place, the Atomic Energy Authority Act No 19 of 1969 governed the nuclear affairs of Sri Lanka until the introduction of Sri Lanka Atomic Energy Act No 40 of 2014. The Atomic Energy Act contained provisions for the establishment of the Sri Lanka Atomic Energy Board, issuance of the license, the establishment of the Sri Lanka Atomic Energy Regulatory Council with specific duties and powers, i.e. powers of the minister, responsibilities and functions of the board, conditions and duties of licensees, termination and appeals of license, safety and security of radioactive sources, import and export regulations of radioactive sources and waste, emergency plan, physical protection of radioactive materials, rules for mining and processing, funds of the authority, the safety of workers etc.

Correspondingly, section 3 of the Atomic Energy Act of Sri Lanka (hereinafter called "the Act"), promoting peaceful and safe use of nuclear energy is a primary objective of the authority. Section 10 discusses the Atomic Energy Regulatory Council's goals established by Section 9. The objectives are to promote the safety of the environment and people from radiation exposure, which is supported by section 13 too. Section 22 shows the rigidity of license issuance, which needed several safety requirements. The duty imposed on license holders by section 24 also promotes environmental and human safety. Section 86(2) (h) says that the minister can make regulations to compensate radiation workers for any injury. Considering all the Acts, even though there are essential provisions included in terms of nuclear practice and regulatory framework, and although there are objectives to adhere to the safety principle of

international nuclear law, there are no provisions regarding compensation for victims exposed to ionizing radiation. Even though there are certain documents to submit to get the license and for the renewal of the license such as the prior notification, practice intended, application for approval for importation, building plan in line with safety measures, proof of sufficient technically qualified staff, proof for adequate safety measures, emergency response plan, and application for the license of nuclear practice in the licensing procedure (Section 22 (1), Sri Lanka Atomic Energy Act of 2014), the Sri Lanka Atomic Energy Regulatory Council does not require insurance coverage or proof of back-up fund for compensation for third-party victims such as workers of the installation.

Sri Lanka is a state party to the Convention on Early Notification of a Nuclear Accident, Convention on Nuclear Safety, and Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency that are not included in the provisions to compensate victims.

4. CONCLUSION AND RECOMMENDATIONS

In making nuclear liability legislation and legal framework, a few key elements should be included granting justice to victims. Those are unlimited compensation in amount, absolute/ strict liability, equitable period of liability, responsibility of other responsible parties, neutral tribunal, backup fund, applicable law/jurisdiction, broad definition of recoverable damages, just standing and access to justice, rules on burden of proof and causation.

The compensation amount should not be limited. The discretionary power to decide the compensation amount should lie upon the courts as the State or a nuclear operator can choose not the monetary value of a person or their health. A problem may arise when the nuclear operator cannot get insurance for an unlimited value. The insurance coverage for third-party bodily injuries/ damages is unlimited in general insurance terms and principles. Therefore, it would

lead operators to be responsible for safety measures. Otherwise, having insurance and limitations on compensations, the operator can insure for the entire liability and neglect the safety measures.

Absolute liability has to be governed as the nuclear operator should bear the strict liability. It is imperative to understand that in some cases like natural disasters, the government has to accept the liability proportionately with the nuclear operator, where damage to the nuclear installation happens even though the operator has followed necessary guidelines given in the event of a natural disaster, as the nuclear operator pays taxes to the government. An equitable period for nuclear damage claims shall exist as some diseases may be latent. The fair period should be decided by the court case by case, based upon the dose of radiation, the surroundings of the disaster, the size of the catastrophe, elements and isotopes used in the reactors, the nature of the people surrounding, distance from contaminated plant and especially on specialist advice given before the courts as an official recommendation.

A neutral tribunal is necessary as some radioactivity damages will not harm people physically. Focusing and granting judgments merely on physical impairments means nothing regarding nuclear damage as cited in *Merlin v. British Nuclear Fuels PLC* ([1990] 3 All ER 711, 720 -21, [1990] 3 WLR 383) and *Blue Circle Industries plc v Ministry of Defense* ([1998] 3 All ER 385). The legislature shall impose a regulatory requirement for a backup fund to show to get the license as an issue on insurance liability may occur in case of damage arising due to a third-party action on the insurance principle called "insurable interest". The strict liability principle still should exist for the operator. Therefore, the need for a backup fund is critical in this regard. Further, the applicable law should be the law of damaged areas. Many jurisdictions (parties to the Vienna Convention 1963) do not allow for consequent economic damages which must be recovered under the suggested legal framework.

Most importantly, some of radiation-exposed diseases are latent and cannot be identified immediately after a

nuclear disaster. Sometimes these diseases show symptoms a few years later from the nuclear accident. Radiation contamination can last for hundreds of years. Economic losses may not need such a long period to claim damages. Health and life have to be protected for at least 30 years of a period. The crucial point regarding the drawbacks of international conventions is that some of the provisions, as stated above, do not comply with essential elements of a nuclear liability regime.

Sri Lanka is a third-world country that tends to adopt nuclear facilities shortly. Therefore, legal regimes to govern such operations must be established – the Atomic Energy Act of 2014 covers licensing and other regulatory requirements. Also, we need a legal framework to control third-party and civil liability towards the general public, as ionizing radiation may cause several health problems. As a dualist country, Sri Lanka has to make domestic legislation to exercise international treaties which the State ratifies. Therefore, the Sri Lankan legislature shall consider making legislation in line with the Vienna Convention and domestic legislation without the drawbacks of international nuclear liability instruments, as stated in the very previous subtopic, "Drawbacks of international instruments". It is also crucial to note that the essentials of a nuclear liability regime, as mentioned in a subtopic, shall be involved in making a new legislation that fits Sri Lanka. Suggested directive measures may bring adverse results in nuclear investments. However, as "health is wealth", the local legislature should protect the general public following the state policy mentioned in the Constitution of Sri Lanka. The gap in Sri Lankan Law on nuclear liability has been discussed in the paper, and the Sri Lankan legislature shall introduce a separate legislation or an amendment to the present Sri Lanka Atomic Energy Act No.40 of 2014 which consists of the limits and methods of compensation in a radiation expose. The new law shall be rid of the drawbacks of the Vienna and Paris Conventions.

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FACTORS AFFECTING EXCHANGE RATE VARIABILITY IN SRI LANKA: AN AUTOREGRESSIVE DISTRIBUTED LAG APPROACH

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ABSTRACT

A free float in the exchange rate has been recorded in the Sri Lankan rupee over the past few years affecting the Sri Lankan economy to a significant extent. This study intended to examine the factors affecting the exchange rate variability in Sri Lanka during the period from 1991 to 2020. For the study secondary data were obtained from the World Bank and the Central Bank of Sri Lanka. The exchange rate was considered as the dependent variable while inflation rate, merchandise trade, Gross Domestic Product (GDP) growth, foreign direct investments, balance of payments and external debt were considered as independent variables. Augmented Dickey Fuller (ADF) test was used to examine the stationary of the time series data, and Autoregressive Distributed Lag (ARDL) was adopted to figure out the long-run and short-run relationship between the variables. The results of ARDL bound test confirmed that there is a co-integration relationship between the variables, and the results of the error correction model revealed the significant impact of inflation rate, merchandise trade, Gross Domestic Product growth, foreign direct investments, balance of payments and external debt on exchange rate in both short run and long run. In the short run, balance of payment and GDP have no significant impact on the changes in exchange rate, and the results confirmed that there is a Exchange rate indicates negative relationships with external debt, inflation, and merchandise trade. Finally, the results confirmed the exchange rate is in a negative relationship with FDI and GDP in the long run.

KEYWORDS: Exchange Rate, External Debt, Foreign Direct Investments, Inflation, Merchandise Trade

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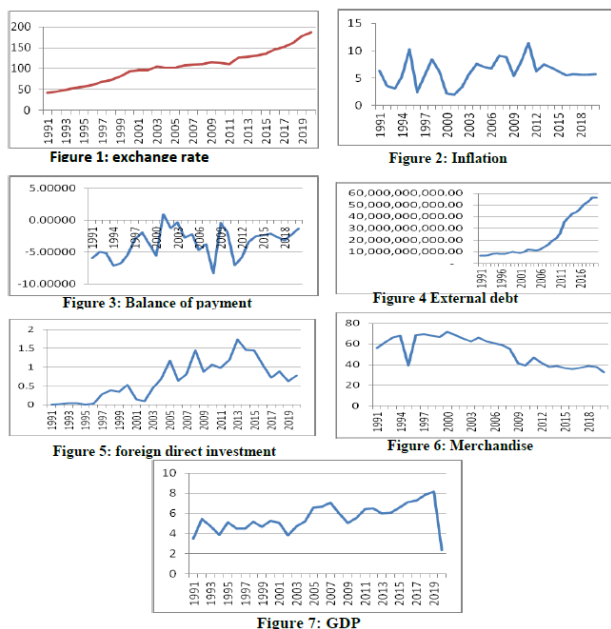


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1. INTRODUCTION

Exchange rate is the most significant macroeconomic indicator which can be used to measure a country's relative level of economic strength. Exchange rate refers to the value of one currency against another currency in macroeconomic review. In the Sri Lankan context, fiscal and monetary policymakers follow the American dollar as the common exchange in currency. The changes in exchange rate will have both favourable and unfavourable impacts on the country's economy and citizens' living conditions because of the comprehensive trade and the financing related to the exchange in currencies. Furthermore, the increase in trend of domestic currency in terms of another currency is referred to as depreciation, and the decrease in the trend of domestic currency in terms of another currency is referred as appreciation. In the Sri Lankan context, it has been recorded an increasing trend in the recent few years. "Since 1948, Sri Lankan foreign exchange has moderately evolved from a fixed rate regime by 1948 to an independently free-floating regime by 2001." Fluctuations in the exchange rate is considered as a critical determinant of the success of fiscal policies of any economy. A free float in the exchange rate has been recorded in Sri Lankan rupee over the past few years, which affected the Sri Lankan economy to a significant extent. As stated below in the literature review, around ninety percent of studies both local and foreign have used the independent variables as differentials in economic growth, differentials in inflation rate, differentials in interest rate and political and economic performances. In the Sri Lankan context, most of the empirical studies have been conducted as partial study of the factors affecting the exchange rate. There was no sufficient literature available to identify the positive impacts and negative impacts on Sri Lankan exchange rate. Thahara, A. F., Rinosh, K. F., & Shifaniya, A. J. F. (2021) has conducted a research on the relationship between exchange rate and trade balance, and the findings of the study have indicated that inflation has a positive impact on trade balance in the short run and that exchange rate and GDP have adverse effect on trade balance in the long run. The researchers have discovered/proved that by using

the auto regressive distributed lag model, bound test approach and error correlation model. Rajakaruna, H. (2017) has conducted a research on investigation of factors affecting exchange rate fluctuations in Sri Lanka and the researcher has stated that there is a positive relationship between exchange rate and foreign purchases as well as a negative relationship with the inflation and the interest rate. by using vector auto regression model. Jayasuriya, D. P. S. H., & Perera, S. S. N. (2016) is another research on analysis of factors affecting USD/LKR exchange rate, and the study has confirmed that increasing net foreign assets and trade balance and decreasing exchange rate has a significant influence on short run appreciation of exchange rate by using Johanson and Juselius cointegration and vector auto regressive model. Wimalasuriya S. (2009) conducted a study on exchange rate pass through: to what extent prices changes in Sri Lanka and the study has investigated the extent to which price changes in Sri Lanka and exchange rate had significant implications on trade by using vector auto regressive approach. Accordingly, it can be derived the fact that the factors affecting exchange variability is still arguable and it is a contradictory area to conduct research on by considering the time period of 1991-2020 by using GDP growth, inflation, FDI, balance of payment and merchandise trade as the determinants of exchange rate and investigate the relationship between the variables and exchange rate. Consequently, the purpose of this study was to investigate the factors affecting the Sri Lankan exchange rate variability and to identify the relationship between those factors. Methods employed to analyse the study were augmented dickey fuller test (ADF) which was adopted to test the stationary property of data, the bound test approach to examine the existence of a long-run relationship among the variables, the unrestricted error correction model (ECM) to test the short-run dynamics of the autoregressive distributed lag model (ARDL) to check the causality relationship between the considered variables. The findings of the study will be beneficial to fill gaps in the exiting literature in exchange rate variability in developing contexts and also will be useful to academicians, new-knowledge seekers, scholars who conduct research on factors affecting fluctuations in Sri



Lankan exchange rate. Also, the findings of this study will help to originate the awareness regarding the exchange rate variability among the fiscal and monetary policy makers to formulate and regulate strategies. The below graphs show the trends of the variables over the past 30 years. There is a definite theoretical connection between exchange rate variability and each of the independent variables have been examined. This indicates that there is a clear and logical correlation between these factors and changes in exchange rates. Exchange rates can be impacted by inflation, which can reduce a currency's purchasing power. Exchange rates and a nation's foreign exchange reserves can be impacted by trade imbalances. A nation's currency's supply and demand are frequently impacted by economic growth. Exchange rates may be impacted by capital flows that FDI brings into the nation. The balance of payments, which shows a nation's economic dealings with other nations, has an impact on exchange rates.

1.1 Research Hypothesis

- H1: Inflation rate significantly impact to exchange rate variability in Sri Lanka.
- H2: merchandise trade significantly impact to exchange rate variability in Sri Lanka.
- H3: Gross Domestic Product (GDP) growth significantly impact to exchange rate variability in Sri Lanka.

- H4: foreign direct investments significantly impact to exchange rate variability in Sri Lanka.
- H5: balance of payments significantly impact to exchange rate variability in Sri Lanka.
- H6: external debt significantly impact to exchange rate variability in Sri Lanka.

1.2 Objectives

To Evaluate the Effect of Exchange Rate Variability on Inflation: Assess the degree to which variations in Sri Lanka's inflation rate impact the country's currency rate volatility.

In order to examine the connection between exchange rate volatility and merchandise trade: Examine the effects of import/export operations and the trade balance on Sri Lanka's exchange rate changes.

In order to investigate how GDP growth affects exchange rate volatility: Examine the connection between GDP growth and exchange rate swings, determining if economic expansion reduces or increases the volatility of exchange rates.

2. LITERATURE REVIEW

2.1 Theoretical review

Many researchers have reviewed the topic of exchange rate and factors affecting the changes of Sri Lankan rupee because it is a comprehensive matter in local as well as international economic studies. Researchers have conducted their studies by using exchange rate as the dependent variable. An exchange rate is the price of one currency expressed in terms of another currency. An exchange rate thus has two components, which are domestic currency and foreign currency, and exchange rate determines how much of one currency has to be given up to buy a specific amount of another currency. The theory had begun to develop in the beginning of 1960.

There are two theories which have been identified under the Exchange trade theory.

1.) Purchasing power parity theory

Purchasing power parity is used to adjust real income per capita. PPP is an economic theory that compares differences between countries' currencies through a basket of goods approach.

2.) Interest rate parity theory

Interest rate parity theory is a theory that differentiates between two countries' interest rates using the exchange rate and local exchange rate system.

Most researchers have considered factors as public debt, interest rate, inflation, and economic performance of the economy. The researches have used the following factors on exchange rate determinants, direct investments, inflation rate, GDP Growth, balance of payment, merchandise trade and external debt which were not mentioned in the published research articles on that topic.

Rajakaruna, (2017) has conducted a study on investigation of Factors affecting exchange rate fluctuations in Sri Lanka which revealed that a negative relationship between the exchange rate and inflation in Sri Lanka.

2.1.1 Direct Investments

In the present study researchers have analysed the relationship between the direct investment and exchange rate variability of Sri Lankan rupee. Jayasekara. (2016) has conducted a study on exchange rate, exchange rate volatility and foreign direct investment in Sri Lanka and the study result has identified that stability of exchange rate and developed facilities were important and helpful to attract direct investment to the country. According to the study of Ranga, & Wijesinghe (2015) on the relationship between foreign direct investment and exchange rate, indicated that there was a beneficial effect to decide the short-term period but there is no high effect on long-term exchange rate to determine foreign direct investment and exchange rate.

2.1.2 Inflation

A country with a constantly lower inflation rate shows an increasing currency as its purchasing power rises relative to other currencies. The inflation rate in a country can have a major influence on the value of the country's money and the foreign exchange rate it has with the currencies of other nations.

2.1.3. GDP Growth Rate

The GDP growth rate measures the yearly (quarterly) change in a country's economic growth efficiency. Lubis, et al (2017) has found that exchange rate depreciation would cause an increase in the country's level of gross domestic production in the research of exchange rate effect on gross product in the case of the five founding members of the Association of Southeast Asian Nations.

2.1.4. Balance of payments

Balance of payments also called as balance of international payments. It consists of current account which is a nation's net trade in goods and services and capital account which is a country's transactions in financial instruments and central bank reserves. Priyatharsiny, (2017) has conducted a research on the impact of exchange rate on balance of payment: an econometric investigation on Sri Lanka, and it has found devaluation under fixed exchange rate regime or allowing depreciation under freely floating exchange rate regime of the domestic currency against foreign currencies can use as a short term and long-term policy measurement to correct the balance of payment imbalance situation. According to the Shabana Parveen et al (2012), it is revealed that inflation is the main factor affecting exchange rate. The study recommends that fiscal policies should be harmonized with monetary policy first and then effective links of both these policies should be made with trade policy. Inflation, growth rate, imports and exports on exchange rate volatility, and growth rate are the primary indicators used to assess variability. The results are analysed using an ordinary least squares (OLS) model of simple linear regression. According to the study, the primary factor influencing Pakistan's exchange rate is inflation. The

study also reveals that economic growth is the second significant factor that affects exchange rate variance, with export and import ranking third and fourth in terms of variation.

The paper titled "Exchange Rate Variability and the Level of International Trade" by Joseph E. Gagnon, published in December 1989 as an International Finance Discussion Paper from the Board of Governors of the Federal Reserve System tackles the effect of the exchange rate variability on international trade, building a theoretical model and calibrating it to observed trade flows and real exchange rates.

Research paper by Juraj Stančík titled "Determinants of Exchange Rate Volatility: The Case of the New EU Members" investigates the factors causing euro exchange rate volatility in six central and eastern European countries that joined the EU in May 2004. The paper analyses the openness of an economy, the "news" factor, and the exchange rate regime for their contributions to exchange rate movements. The TARARCH model is used to model the volatility of exchange rates. The study aims to identify possible sources of the new member countries' failure to maintain stable exchange rates, which is a criterion for joining the EMU. The results suggest that the openness of an economy has a negative effect on exchange rate volatility, and there is a significant effect of "news" on exchange rate volatility.

2. 2 Empirical review

A study on the impacts of exchange rate volatility on Sri Lanka's exports to six developed countries during the flexible exchange rate regime has been conducted by Ekanayake, A. W., & Tsujii, H. (1999), and the estimation has been carried out for the quarterly data, the period of 1978 I, 96II. The study has been focused on six major trading countries with the nominal data on Sri Lanka's exports. The major findings indicated that during the sample period, real exchange rate volatility adversely affected Sri Lanka's exports to the countries under investigation. To test the presence of long run equilibrium relationships between the real exports and the determinants, researchers have used the Johansen-Juselius multivariate co-integration technique and to inspect the short run dynamics

underlying the long run relationships considered the researchers have used the error correction modelling technique. The research about the factors affecting fluctuations in the exchange rate of Polish zloty against the euro in Poland by Twarowska, K., & Kakol, M. (2014) identified financial account balance and inflation rate as the most important factors determining the level of exchange rate. The study suggests that Poland's financial account surplus shows a positive relationship with the country's currency, and that an increase in the inflation rate has a negative effect and reduces the value of Polish currency, and it indicates the market interest rate as the third most important factor explaining that the rises of interest rates contribute to appreciation of Polish currency. Moreover, the study suggests that the government deficit makes a major impact as another variable affecting zloty exchange rate, but the economic growth and the current account are less significant. The above results were found based on the literature review, comparison of statistical data and regression analysis.

The study by Rajakaruna, H. (2017) on "An investigation of factors affecting exchange rate fluctuations in Sri Lanka" has used different econometrics models as Multiple Regression Model (OLS Method), Vector Auto Regression Model (VAR), Impulse Response and Variance decomposition test and diagnostic techniques (Unit-root test, lag selection criteria, AR Roots test) to achieve the objective of the study, and it has found a positive relationship between net foreign purchases and exchange rate and a negative relationship between the exchange rate and inflation, worker remittances respectively according to the empirical results. The study emphasizes the significant impact of most of the variables on the exchange rate by showing a peak effect within a two-month lag and 1.60 from the Durbin Watson Statistic which suggested that the relevant variables have been included in this study. The research related to the relationship between exchange rate and trade balance: empirical evidence from Sri Lanka by Thahara, A. F., Rinosha, K. F., & Shifaniya, A. J. F. (2021) demonstrates the correlation between exchange rate and trade balance using exchange rate

as the main independent variable and gross domestic product, inflation as control variables from the year 1977 to 2019. Methods employed to analyse the study were ADF unit root tests adopted to test the stationary property of data, the Bound test approach to examine the existence of a long-run relationship among the variables, the unrestricted Error Correction Model (ECM) to test the short run dynamics of the ARDL model and the Granger Causality Test to check the causality relationship between the considering variables. The study illustrated that the inflation has a positive impact on the trade balance in the short run and the exchange rate has a negative impact on trade balance in the long run. Moreover, it was found that the exchange rate is higher than one which is consistent with the Marshal Lerner Condition (MLC) and also that there is an adverse effect on the trade balance by GDP in the long run while having an import dependent economy in Sri Lanka which creates a trade deficit. The coefficient of trade balance and exchange rate (at lag 1) were positive – significant and negative respectively in the previous year.

3. METHODS

This study analyses the factors affecting the exchange rate variability of Sri Lanka. The authors have found that there was an upward trend in the exchange rate of Sri Lanka in the past few years (Figure 01). The researchers conducted this study to figure out the main reason for factors affecting exchange rate variability by analysing exchange rate and variables together. This Research is mainly based on the deductive research approach. Researches adopted a quantitative approach for this study. This research is based on secondary data series from 1991 to 2022. The authors have considered yearly data of each dependent and independent variable from 1991 to 2022. As a dependent variable, Sri Lanka’s exchange rate data collected from world development indicators and other independent variables as Sri Lanka’s GDP, external debt, inflation rate, foreign direct investments, the balance of payment, merchandise trade data collected from the central bank of Sri Lanka and world development indicator. Furthermore, researchers have added a graphical

representation of each variable for the study. The authors have applied the ADF test for the research to measure the stationary of the data set. Then, the optimal lag length selection method was applied to select the optimal lag value for the next steps of the analysis. Logarithms were used to analyse the data because there may be some variables having skewed distribution which may be either positive or negative. The balance of payment recorded a negative value in several years. It will occur as an error in the model. Logarithms were used to reduce errors and to make the distribution a normal one. ARDL model was applied for the study to find out the long-run relationship between variables. Then, the Error correction model was used to estimate the short-run relationship of the exchange rate with inflation, GDP, external debt, merchandise trade, FDI, and balance of payment.

3.1 Conceptual Diagram

The Researchers developed the conceptual diagram below according to the empirical findings.

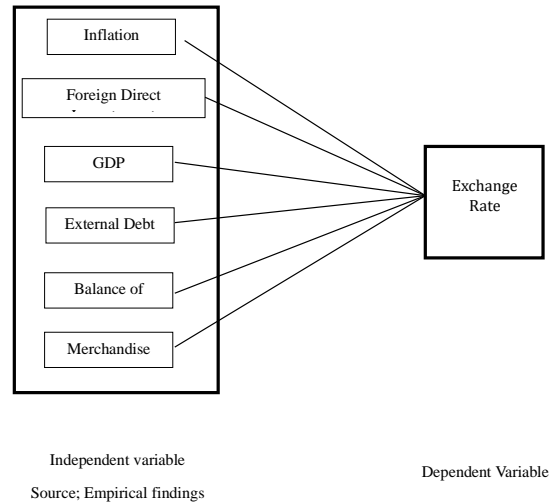


Figure 8: Conceptual Model (Source; Empirical findings)

3.2 Log-log model

The empirical model reflecting the effect of the independent variables on the exchange rate can be demarcated as follows.

$$\ln(ER)_t = \beta_0 + \beta_1 \ln BOPt + \beta_2 \ln EDt + \beta_3 \ln FDI_t + \beta_4 \ln GDP_t + \beta_5 \ln INF_t + \beta_6 \ln MT_t + \epsilon$$

Where:

ER = Exchange rate fluctuation

β_0 = Constant

BOP = Balance of payment

ED = External debt

FDI = Foreign direct investments

GDP = Gross Domestic Production

INF = Inflation

MT = Merchandise trade

Σ = Error term

4. DATA ANALYSIS AND RESULTS

According to the secondary data collected (Figure 01 - 06), the Balance of payments of Sri Lanka has recorded negative values in the past 30 years. Only 2001 has recorded a positive value for the balance of payments, and all the other years have recorded negative values. The GDP shows an increasing trend from 1991 to 2019, and after 2019 GDP growth rate has rapidly dropped from 8.15 to 2.37. The main reason for this dropdown is the COVID-19 pandemic situation. It has had an impact on all economies of the world. Economies have had to stop their production for a while, and thus it has impacted on all economies. The external debt also recorded an increasing trend year by year as Sri Lanka has borrowed more and more from foreign lenders. The merchandise Trade has recorded a decreasing trend through the past 30 years. The dependent variable, the exchange rate has recorded a continuously increasing trend in the past 30 years.

4.1 Unit Root Test Analysis

Augmented dickey fuller test and Phillips's person unit root tests were used to prove whether the data series is stationary or not. For this study, the authors have been used the ADF test to measure the stationary of data series. Below the table 1 shows the ADF statistic and probability result of the selected data series. According to table 1, the data series shows the different results of stationary and non-stationary data. Authors have been taken ADF test results at level series and first difference. The probability value of each and every variable determines whether each variable is stationary or nor, with each variable under

a 5% significance level. As the decision row of Table 1, the *lnED* variable is not showed any stationary value at level series and first difference under 5% significance level. *lnED* probability value is higher than 0.05 significance value. Other variables, *lnFDI*, *lnER*, *lnGDP* and *lnMT* stationary at the first difference series under a 5% significance level. Under 5% significance level, *lnBOP* and *lnINF* variables are stationary at both level series and first difference. Therefore, the results show mixed integration order of data series. As a result of that authors has been decided to use ARDL co-integration model for this research.

Table 1. Augmented Dickey Fuller (Source: Calculated by author using EViews.)

Variable	Level series		First difference Series		Decision
	ADF Statics	Pob Value	ADF Statics	Prob Value	
<i>lnER</i>	1.1968	0.9973	-4.5673	0.0011	stationary at 1st difference
<i>lnBOP</i>	-3.8620	0.0064	-5.2116	0.0003	stationary at 1st difference and level series
<i>lnED</i>	0.5084	0.9840	-2.8061	0.0702	not stationary at any level
<i>lnFDI</i>	-1.8733	0.3395	-6.5454	0.0000	stationary at 1st difference
<i>lnGDP</i>	-2.9268	0.0545	-3.5664	0.0134	Stationary at 1st difference
<i>lnINF</i>	-3.8884	0.0060	-7.2579	0.0000	stationary at 1st difference and level series
<i>lnMT</i>	-1.4376	0.5501	-5.9996	0.0000	stationary at 1st difference

4.2 Optimal lag length selection

The first step of the ARDL bound test is selecting an optimal number of lags. Optimal lag selection is important to continue the accuracy of the model and generate correct estimated results. The study has been considered five criteria named as, sequentially modified LR test statistic (LR) (each test at 5% level), final prediction error (FPE), Akaike information criterion (AIC), Schwarz information criterion (SC), and Hannan-Quinn information criterion (HQ). According to Table 2, all five criteria recommended

Table 2 optimal lag length

Lag	LogL	LR	FPE	AIC	SC	HQ
0.00E+00	-110.1049	NA	235.5866	8.293209	8.578682	8.380481
1	-75.14745	52.43622*	20.91828*	5.867675*	6.200726*	5.969492*
2	-74.82799	0.456375	22.08207	5.916285	6.296915	6.032647

one (1) lag as optimal lag length according to VAR calculated data. Authors applied Lag 01 for *lnER*, *lnBOP*, *lnED*, *lnFDI*, *lnGDP*, *lnINF* and *lnMT* variables.

4.3 ARDL Bound Test

Authors have used ARDL model for the study to estimate co-integration between the variables. For this study, exchange rate (*lnER*) has been considered as the dependent variable and balance of payment (*lnBOP*), external debt (*lnED*), foreign direct investments (*lnFDI*), gross domestic product (*lnGDP*), inflation rate (*lnINF*) and merchandise trade (*lnMT*) have been considered as the independent variables.

Although ARDL models have been used in econometrics for decades, they have gained popularity in recent years as a method of examining co-integrating relationships between variables through the work of persaran and shin (PS and Persaran1998, shin and smith 2001).

The Table 3 shows the ARDL (1, 1, 1, 1, 1, 1) bound test results. I (0) indicates lower bound regression results and I (1) indicates upper bound regression results. If the F-statistic value or T-statistic value is higher than the lower bound value (I (0)). It means there is co-integration among variables. If F-statistic value or T- statistic values are higher than the upper bound test value (I (1)) it confirms that there is co-integration between variables. According to the calculated data of the study, the F-statistic value takes 7.365and it is higher than lower bound 3.15 and upper bound 4.43 at a 1% significance level. Furthermore, T- statistic value takes -9.498, which is higher than the lower bound value and upper bound value at a 1% significance level. These results verify that there is co-integration between variables. It exists there is a

Table 3. Results of ARDL bound tests

Selected model: ARDL (1,1,1,1,1,1)				
F-bounds test		Null hypothesis: no levels relationship		
Test statistic	Value	Significance	i(0)	i(1)
F-statistic	7.365	10%	2.12	3.23
K = 6		5%	2.45	3.61
		2.50%	2.75	3.99
		1%	3.15	4.43
T-bounds test		Null hypothesis: no levels relationship		
Test statistic	Value	Significance	i(0)	i(1)
T-statistic	-9.498	10%	-2.57	-4.04
		5%	-2.86	-4.38
		2.50%	-3.13	-4.66
		1%	-3.43	-4.99

(Sources: Calculated by author using EViews).

Table 4 Estimated long run coefficient using the ARDL model

Selected Model: ARDL (1, 1, 1, 1, 1, 1) ; Dependent Variable is Exchange rate				
Variable	Coefficient (5% Significant level)	Std. Error	T-Statistic	Probability
<i>LnBOP</i>	-0.409***	0.320	--1.277	0.237
<i>LnED</i>	0.000***	0.000	5.669	0.000
<i>LnFDI</i>	-12.48***	2.850	-4.378	0.002
<i>LnGDP</i>	-2.817***	1.307	-2.155	0.063
<i>LnINF</i>	2.835***	0.915	3.097	0.014
<i>LnMT</i>	1.053***	0.233	4.518	0.002

Sources: Calculated by author using EViews.

long-run equilibrium relationship among variables.

4.4 Long Run Estimation

Table 4 shows the results of the estimated long-run coefficient of variables. According to the below table 4, it demarcates the results of the estimated long-run coefficient of variables. And as well, the Balance of payment (*lnBOP*) probability value takes 0.23 which is higher than the 5% significance level in long run. It means the change of balance of payment is not impacted by the changes in the exchange rates in Sri Lanka within the past 30 years. It seems that the most of the economic transactions of Sri Lanka have not impacted by the changes in the exchange rate. As per the calculated data, external debt (*lnED*), inflation rate (*lnINF*) and merchandise trade (*lnMT*) recorded positive coefficient values. It means that the exchange rate and external debt (*lnED*), inflation rate (*lnINF*), and merchandise trade correspondent to each other in long run. If Sri Lanka increases the portion of debt borrowed from foreign parties, it will lead to an increase in all the prices of the economy with respect to all imports and exports of the country, then the exchange rate has been impacted. It has been increased. In addition to that, if the exchange rate getting decrease, as a result of that, external debt (*lnED*), inflation rate (*lnINF*) and merchandise trade (*lnMT*) show a decreasing trend. Moreover, foreign direct investments (*lnFDI*) and GDP (*lnGDP*) Long-run coefficients show a negative relationship with the exchange rate. It means, there is an inverse relationship in between exchange rate and foreign direct investments (*lnFDI*), GDP (*lnGDP*). When increasing foreign investors' investments in Sri Lanka by 2.817%, the exchange rate decreased by 1% through the past 30 years of Sri Lanka. Moreover, when increasing the gross domestic products of Sri Lanka by 12.48%, leads to a decrease of exchange rate by 1%.

4.5 Short run relationship

Authors estimate the relationship between the variables in the short run by using the Error Correction Model. Table 5 represents the variables' results of ECM. According to the below table, gross domestic product (change in *lnGDP*) value is 0.474 which is higher than the 5% significance level. It means in the short run, GDP is not impacted by the

changes in the exchange rate. Furthermore, the balance of payment (Change in *lnBOP*) is not impacted by the changes in exchange rate either short

Table 5 - Error correction representation for the selected ARDL model

Selected Model: ARDL(1,1,1,1,1,1) ; Dependent Variable is <i>lnER</i>				
Variable	Coefficient 5% Significant level	Std. Error	t-Statistic	Probability
<i>DlnER</i>	-0.503***	0.134	-3.752	0.005
<i>DlnED</i>	-0.000***	0.000	-4.594	0.001
<i>DlnFDI</i>	4.910***	1.630	3.011	0.016
<i>DlnGDP</i>	-0.225***	0.300	-0.749	0.474
<i>DlnINF</i>	-2.530***	0.375	-6.732	0.000
<i>DlnMT</i>	-0.603***	0.117	-5.149	0.000
R-squared	0.946	Mean dependent variables		5.069
Adjusted R-squared	0.900	S.D. dependent variables		5.098
S.E. of regression	1.610	Akaike info criterion		4.096
Sum squared residuals	36.304	Schwarz criterion		4.720
Long likelihood	-42.308	Hannan-Quinn criterion.		4.282
		Durbin-Watson statistic		2.798

run or long run (table 4 and 5). The changes of the other variables such as, external debt (change in *lnED*), foreign direct investments (change in *lnFDI*), inflation rate (change in *lnINF*), and merchandise trade (change in *lnMT*) can impact to have changes in the exchange rate in Sri Lanka in the short run. External debt (change in *lnED*), foreign direct investments (change in *lnFDI*), inflation rate (change in *lnINF*), and merchandise trade (change in *lnMT*) probability values are 0.001, 0.016, 0.000, and 0.000 respectively. The probability values of these variables are lower than 5% significance level. It means that in the short run, external debt (change in *lnED*), foreign direct investments (change in *lnFDI*), inflation rate (change in *lnINF*), and merchandise trade (change in *lnMT*) variables have been impacted

on changes in the exchange rate. The authors have found that the foreign direct investments (change in $\ln FDI$) show a positive coefficient value in the short run. It means in the short run when increasing the investments from foreign investors to the Sri Lanka, it will lead to increase exchange rate.

On the other hand, inflation rate (change in $\ln INF$) merchandise Trade (change in $\ln MT$), external debt (change in $\ln ED$) variables have recorded negative coefficient value in short run. It means when the inflation rate (change in $\ln INF$) merchandise trade (change in $\ln MT$), external debt (change in $\ln ED$) increase, it leads to a decreased exchange rate in the short run.

5. DISCUSSION

Rajakaruna, H. (2017) has conducted a research on factors affecting exchange rate fluctuations in Sri Lanka by using a multiple regression model and VAR model. The study resulted that there was a negative relationship between inflation and the exchange rate. These results are similar to the authors' results because the authors' found that there has a negative relationship between the exchange rate and inflation rate in the short run. In the long run, foreign direct investment shows a negative relationship with the exchange rate. An increase in FDI leads to an increase in the exchange rate. Furthermore, in the short run, FDI showed a positive relationship with the exchange rate.

The authors' results are similar to the previous finding of researcher Jayasekara S. G. S. D. (2016). The researcher Jayasekara S. G. S. D. (2016) has conducted the study by using Zellner's seemingly unrelated regression model. The calculated results of the authors' are similar to the researcher's results in the short-run and long-run. The study found that there is a positive relationship between FDI and exchange rate in short run. This result is similar to the authors' results. Another researcher Rajakaruna, H. (2017) conducted a research "An investigation of factors affecting exchange rate fluctuations in Sri Lanka *Journal of South Asian Studies*, 5(2), 101-115". The researcher found that there is a negative relationship

between inflation and exchange rate. These results are similar to the authors' results. Because the authors' found that there is a negative relationship between exchange rate and inflation rate in short run. According to the previous studies, Priyatharsiny, S. (2017) has conducted a research on the impact of the exchange rate on the balance of payment (BOP) by using Johansen co-integration, study found that there was a co-integration relationship in long run. According to the calculated results, the authors have found that the balance of payment has not impacted exchange rate volatility in either the short run or long run.

There was a contradiction between the Authors' study results and Priyatharsiny, S.'s (2017) study results. Aslam, A. M. (2016) has conducted research to examine the impact of exchange rate on economic growth in Sri Lanka by using a multiple regression model. This researcher found that there was a positive relationship between GDP and exchange rate. But, according to the authors' calculated results, there was no relationship between GDP and exchange rate in the long run. In the short run, there was no relationship because the probability exceeds the 5% significance level. There is a contravention between these two studies' results. There was no previous study that examined the relationship between exchange rate and external debt as well as relationship between exchange rate and merchandise trade in Sri Lanka. According to the Authors' results, the external debt and exchange rate have a positive relationship in the long. In the long run, the increase in Sri Lanka's borrowings from external parties leads to an increase in the exchange rate. After 2006 the external debt of Sri Lanka rapidly increased. It leads to an increase in the exchange rate also. And in the short run, it showed a negative relationship.

Merchandise trade and exchange rate showed positive co-integration in long run. It means an increase in merchandise trade imports and exports leads to increase the exchange rate in Sri Lanka. In the short run, it showed negative co-integration It means an increase in merchandise trade imports and exports leads to decrease the exchange rate in Sri Lanka. There were variations in Sri Lanka's inflation

rate during the COVID-19 period. At first, we saw an increase in inflation, especially for necessities, as demand patterns and supply chains were altered. However, inflation rates stabilised as the government put policies in place to limit inflation, such as supply chain management and price restrictions. Data on Sri Lanka's merchandise commerce during the epidemic revealed difficulties brought on by interruptions in the world's supply chains. There were obstacles to exports, particularly in the textile and clothing sector, which accounts for a sizable portion of the nation's exports. In the meantime, imports of necessities like medical supplies and pharmaceuticals rose to keep up with the pandemic's demands. A trade imbalance resulted from these trade dynamics. The rate of GDP growth in Sri Lanka was considerably impacted by the COVID-19 pandemic. Early in the epidemic, the economy contracted as a result of lockdowns and disruptions to business operations. But when the constraints loosened, several industries gradually recovered. The data illustrates how resilient and flexible the nation has become in the face of adversity.

FDI inflows to Sri Lanka fluctuated throughout the COVID-19 pandemic. In the early months of the crisis, FDI decreased as a result of the pandemic's uncertainty. FDI showed indications of revival as the world economy steadied and Sri Lanka took steps to entice investment. The balance of payments statistics exposed weaknesses in the foreign sector of Sri Lanka. Throughout the epidemic, the trade deficit and falling tourism income made it difficult for the nation to maintain a steady balance of payments. Data on Sri Lanka's external debt levels showed that the nation was dependent on outside funding to lessen the pandemic's economic effects. Taking on more debt increased worries about the sustainability of debt levels even if it was necessary to support the economy. currency Rate: The dynamics of the independent variables were closely associated with the behavior of Sri Lanka's currency rate. The Sri Lankan Rupee was initially under pressure to depreciate due to currency rate fluctuations brought on by trade imbalances, economic contractions, and pandemic fears. However, the central bank put in place a number of measures to keep the exchange rate

stable, such as capital controls and forex market interventions, which over time helped to stabilize the exchange rate to some extent.

6. CONCLUSION AND IMPLICATIONS

This study analyzes the factors affecting the exchange rate variability of Sri Lanka. The authors have considered exchange rate as the dependent variable, and inflation, foreign direct investments, GDP, inflation rate, merchandise trade, and external debt as independent variables. The authors have been taken secondary data for the study from 1991 to 2020. The study has applied the ARDL model for the calculations. ADF test confirms that the variables are stationary or non-stationary. According to the lag selection criteria, for the study authors have used one lag as optimal lag selection. Then authors applied long run bound test to measure the long-run co-integration and the error correction model to measure short-run co-integration. According to results, in the long run, the balance of payment has impacted changes in the exchange rate in Sri Lanka. External debt a positive impact on the exchange rate. When external borrowing increases, the exchange rate also increases in Sri Lanka in the long run. Foreign direct investments made a negative impact on the exchange rate. An increase in foreign direct investment leads to a decrease in the exchange rate in Sri Lanka. In the long run, there was a negative relationship between gross domestic products and the exchange rate in Sri Lanka. This result was not similar to one of the previous findings. The inflation rate made a positive impact on the exchange rate in Sri Lanka in past years. When the inflation rate increase, the exchange rate also increases. The merchandise trade also made a positive impact on the exchange rate. When increasing imports and exports in Sri Lanka the global, the exchange rate also increases.

In the short run, the authors found that the balance of payment significantly has an impact on the change in the exchange rate. External debt made a negative impact on the exchange rate in the short run. It means, that in the short run when foreign borrowing increases the exchange rate decrease. The foreign

direct investments made a positive impact on the exchange rate in the short run. This result was similar to one of the previous findings result of Jayasekara S. G. S. D. (2016). Also, the author found that in the short-run gross domestic product was not impacted by changes in the exchange rate in Sri Lanka. The inflation rate made a negative impact on the exchange rate in Sri Lanka. Merchandise trade also made a negative impact on the exchange rate in Sri Lanka. Authors majorly found that the balance of payment has not impacted changes in Sri Lanka in either the short run or the long run. Also, external debt and merchandise trade positively impacted to exchange rate in the long and negatively impact on the exchange rate in the short run.

Policy implications of Finding

This research finding will be helpful for the academicians, new knowledgeable scholars, and government policy makers to efficient and effective decisions. And also the findings will be beneficial to fulfill the dearth in the exiting literature gap in exchange rate variability in developing context. First, the findings suggest that the Sri Lankan exchange rate is sensitive to a number of macroeconomic factors, including inflation, the trade balance, and interest rates. This suggests that policymakers should carefully monitor these factors and take steps to address them if they are a source of exchange rate instability.

Second, the findings suggest that exchange rate variability can have a significant impact on economic growth. This is because exchange rate variability can make it difficult for businesses to plan and invest, and it can also lead to uncertainty and risk aversion among consumers. Therefore, policymakers should take steps to reduce exchange rate variability whenever possible.

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ANALYZING THE EFFICACY OF *Salvinia molesta* AND *Pistia stratiotes* AS PHYTOREMEDIATION AGENT FOR HEAVY METALS

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ABSTRACT

To rejuvenate our declining ecosystems, it is imperative to promptly face the issue of heavy metal contamination, which serves as the underlying cause for pollution globally. Phytoremediation, which is the ability of certain plants to accumulate, break down, or neutralize pollutants in water, soil, or air, offers a promising solution. The current investigation aimed to assess the efficacy of *Salvinia molesta* and *Pistia stratiotes* in removing heavy metals from apparel industrial wastewater. In a controlled indoor environment, the wastewater underwent treatment using these plants, while control tanks of the same size without any plants were maintained for comparison. This setup included three replicates for each treatment. Over 18 days, samples of the wastewater were collected and analyzed for the presence of Cadmium (Cd), Copper (Cu), and Zinc (Zn) using an Atomic Absorption Spectrophotometer (AAS) every three days. An initial analysis of the untreated wastewater was conducted. Statistical analysis employed one-way ANOVA to compare the average concentrations in the effluent and the removal percentages across various treatment conditions. *Pistia stratiotes* exhibited a higher Cd reduction rate (29.97%) compared to *Salvinia molesta* (18.13%). Tanks containing *Salvinia molesta* showed a more substantial Cu removal rate (52.47%), while *Pistia stratiotes* demonstrated a lower Cu reduction (42.37%). As for Zinc (Zn), it decreased by 22.89% and 17.87% in tanks where *Salvinia molesta* and *Pistia stratiotes* were used, respectively. This study, conducted over an 18-day trial period, underscores the effectiveness of both plant types in removing Cd, Cu, and Zn from the wastewater. The preferential absorption was observed for Cu over the other two metals. For *Salvinia molesta*, the removal efficiency followed the sequence: Cu>Zn>Cd, whereas for *Pistia stratiotes*, it was Cu>Cd>Zn. These findings demonstrate that both plant species can thrive while accumulating these heavy metals in apparel industrial wastewater.

KEYWORDS: Atomic Absorption Spectrophotometer, Hydrophytes, Metals, Phytoremediation, Wastewater

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1. INTRODUCTION

Despite regional variations in pollution intensity and levels, heavy metal contamination is a worldwide problem. At least 20 metals are categorized as hazardous, and a half of them are released into the environment at levels that are very dangerous to human health (Akpor and Muchie, 2010; Ajayi and Ogunbayio, 2012; Roy *et al.*, 2018). Strong metals and metalloid contamination has been caused by rapid population increase, deforestation, urbanization, industry development, exploration, and exploitation of the environment (Ajayi and Ogunbayio, 2012; Balamoorthy *et al.*, 2022; Ullah *et al.*, 2022). Both people and other living things can become unhealthy after being exposed to heavy metals. Additionally, this category of pollutants has the potential to increase fatalities and the prevalence of severe, fatal diseases (Balamoorthy *et al.*, 2022). Acute poisoning in people can result in serious failure of the liver, brain, kidneys, reproductive system, and nervous system (Moktar and Mohd Tajuddin, 2019).

Toxic heavy elements like Cadmium (Cd), Zinc (Zn), Chromium (Cr), Lead (Pb), and Copper (Cu) serve as instances of harmful heavy metals that are well-known for their detrimental impact on the environment (Balamoorthy *et al.*, 2022). Because of their persistence, biomagnification, and accumulation in the food chain, the disposal of heavy metals without effective treatment creates a serious risk to public health (Ekanayake and Manage, 2017; Roy *et al.*, 2018; Balamoorthy *et al.*, 2022). Cancer, organ damage, nervous system impairment, and restricted growth and development are just a few of the serious consequences (Ajayi and Ogunbayio, 2012; Akpor and Muchie, 2010; Roy *et al.*, 2018). The contamination by these metallic elements has adverse effects on the ecosystem and contributes to the issue of global warming (Balamoorthy *et al.*, 2022). Therefore, it necessitates the implementation of measures to mitigate metal pollution.

For the purpose of removing heavy metals from leachate, a variety of techniques have been developed, including chemical precipitation, chemical oxidation or reduction, electrochemical treatment, ultrafiltration, reverse osmosis, electro-dialysis, the use of membrane

technology, solvent extraction, evaporation recovery, and ion exchange process (Ajayi and Ogunbayio, 2012; Victor *et al.*, 2016; Sadi *et al.*, 2018; Ekanayake and Pathmalal, 2020; Singh *et al.*, 2021; Balamoorthy *et al.*, 2022). Although the technologies indicated above have been shown to remove contaminants, they are very expensive, may produce a huge amount of waste, and are therefore not economically viable (Moktar and Mohd Tajuddin, 2019). Strategies are being examined and improved to address this environmental concern system (Moktar and Mohd Tajuddin, 2019). The most popular treatments fall into the recycling, filtration, biological, and chemical categories, although phytoremediation and the employment of plants in the purification process have drawn interest as a potential solution (Singh *et al.*, 2021; Ting *et al.*, 2020).

Using a cutting-edge technique called phytoremediation, pollutants can be removed from soils, air, groundwater, and surface water (Moktar *et al.*, 2018; Moktar and Tajuddin, 2019; Ekanayake *et al.*, 2021; Singh *et al.*, 2021; Ting *et al.*, 2020). In the wastewater treatment industry, phytoremediation has gained attention as a new emerging green technology because of a variety of advantages, most notably low operating costs and environmental friendliness (Jayaweera and Kasturiarachchi, 2018; Ting *et al.*, 2020; Ekanayake *et al.*, 2021). Phytoremediation encompasses a series of techniques, including rhizosphere biodegradation, phytostabilization, phytoextraction, rhizofiltration, phytovolatilization, phytodegradation, and hydraulic control (Balamoorthy *et al.*, 2022). This technique makes use of the organic and inorganic pollutants that macrophytes and the microbial rhizosphere flora of their roots naturally break down and sequester (Seguil *et al.*, 2022).

Phytoremediation technology involves the direct use of different plant species to absorb, gather, detoxify, and neutralize contaminants in soils, sediments, wastewater, surface water, or groundwater, employing physical, chemical, and biological processes (Roy *et al.*, 2018; Seguil *et al.*, 2022). This approach not only helps protect the environment but also does so in a cost-effective manner, as noted by Lakshmi *et al.* in 2017. Many plants previously recognized for their

remarkable ability to absorb and store diverse toxic metals are currently under assessment for their involvement in the process of phytoremediation, which aims to purify soils and water contaminated with trace elements (Balamoorthy *et al.*, 2022). Plant roots absorb pollutants, which accumulate in bodily tissues before gradually decomposing into less harmful forms (Seguil *et al.*, 2022).

Terrestrial plants play a vital role in purifying both contaminated soil and water by accumulating heavy metals in their tissues, as demonstrated by Balamoorthy *et al.*, 2022. In the case of aquatic phytoremediation plants, which are components of aquatic treatment systems, their primary goal is to eliminate pollutants from wastewater by utilizing naturally or artificially moist soils (Seguil *et al.*, 2022). These aquatic plants effectively remove pollutants like heavy metals, organic and inorganic contaminants, and pharmaceutical residues from various sources of wastewater, including industrial, domestic, and agricultural sources (Mustafa and Hayder, 2021).

Research suggests that aquatic macrophytes efficient at wastewater treatment in comparison to terrestrial plants due to their rapid growth, increased biomass production, greater capacity for absorbing pollutants, and their ability to enhance purification when in direct contact with contaminated water, as observed in the study by Wickramasinghe and Jayawardana, 2018. These aquatic plants are essential components of freshwater ecosystems as they provide food, shelter, structure, and coverage for a variety of terrestrial and aquatic animal species (Seguil *et al.*, 2022). In the context of phytoremediation, free-floating aquatic plants are considered more suitable due to their ready availability, high productivity, and their capacity to store and harvest pollutants (Mustafa and Hayder, 2021).

Numerous researchers have examined and assessed the effectiveness of aquatic macrophytes in wastewater treatment (Ekperusi *et al.*, 2019; Kaflea *et al.*, 2022; Mustafa *et al.*, 2022). Various types of aquatic plants, both free-floating and submerged, such as *P. stratiotes*, *S. molesta*, *Lemna* spp., *Azolla pinnata*,

Landoltia punctata, *Marsilea mutica*, *Eichhornia crassipes*, *Spirodela polyrhiza*, and *Riccia fluit*, as well as emergent plants like *Hygrophilla corymbosa*, *Ruppia maritima*, *Najas marina*, *Hydrilla verticillata*, *Egeria densa*, *Vallisneria americana*, and *Myriophyllum aquaticum*, were utilized for wastewater treatment. Additionally, other plant species, including *Cyperus* spp., *Iris virginica*, *Nuphar lutea*, *Imperata cylindrical*, *Justicia americana*, and *Diodia virgin*, were employed (Ekperusi *et al.*, 2019).

Because of the adverse impact of its secondary effluent on the environment, the techniques could potentially become costly and economically impractical. Hence, it remains imperative to establish a cost-effective wastewater treatment method. Heavy metal removal efficiencies can vary widely depending on the plant species used for the phytoremediation. According to the literature, *Salvinia molesta* and *Pistia stratiotes* have not been extensively researched to comparative treatment of apparel industrial wastewater from the apparel industry in Sri Lanka. Therefore, the goal of the present study is to evaluate the potential of *Salvinia molesta* and *Pistia stratiotes* phytoremediation capabilities for biologically removing heavy metals from low-concentrated wastewater generated from an apparel industry in Sri Lanka.

2. METHODOLOGY

After selecting suitable aquatic plants for the experiment, same sized, small and healthy plants were kept in tap water for seven days to acclimatize. Raw wastewater from an apparel company in Sri Lanka was collected and diluted appropriately (Raw wastewater 1: Tap water 4). Then, sampling was conducted every three days for 18 days of the experiment. Thereafter, wastewater samples were analysed for heavy metals over time.

At the end of the experiment, percentage reductions of heavy metals were determined for each plant species. The data was subjected to one-way analysis of variance (ANOVA), and findings were deemed statistically significant if the p-value was less than 0.05.

A. Selection and collection of plants

The ideal plant species for phytoremediation should have a wide distribution in nature, be easy to cultivate, yield a lot of biomass, be immune to the harms caused by metals and pollutants, and have a high absorption (Ekanayake *et al.*, 2021; herbivores; Kafle *et al.*, 2022; Ullah *et al.*, 2022.). Due to their availability and to assess how these plants respond to low concentrated industrial effluent from the textile industry, *Salvinia molesta* and *Pistia stratiotes* were chosen for the present investigation. *Salvinia molesta* and *Pistia stratiotes* plants were gathered in a plastic container in a nonpolluted environment. Then, they were kept until they were carried to the location for stabilization. Both plant species were small, healthy, and of the same size.

B. Stabilization of selected aquatic plants

Young and healthy aquatic plants of the same size were collected from their sources. Then, their bodies and roots were completely cleaned to remove dirt, any trapped material, and any macrophyte debris. Before the experiment, plants were thoroughly cleansed and cleaned with tap water (Victor *et al.*, 2016; Wickramasinghe and Jayawardana, 2018; Mustafa and Hayder, 2020). Two large plastic bowls filled with tap water were used to maintain the plants (Nizam *et al.*, 2020).

Healthy young plants were chosen for the experiment, and dead leaves were taken out (Kumar and Deswal, 2020). For seven days, collected plants were stabilized in tap water for stabilization (Wickramasinghe and Jayawardana, 2018; Mokhtar and Tajuddin, 2019; Singh *et al.*, 2021).

C. Collection of wastewater

Grab sampling technique was used to collect raw wastewater from the inlet of the sewage treatment plant of an apparel industry into a container. Heavy metals including Cu, Cd, and Zn in the collected raw wastewater were assessed using an Atomic Absorption Spectrophotometer (Varian AA240FS).

D. Experimental setup

An indoor setup was created so that the plants would cooperate with natural processes and receive enough

aeration and sunlight (Mokhtar *et al.*, 2018; Kafle *et al.*, 2022). Before the experiment, the undiluted raw wastewater was adequately diluted (Raw Wastewater 1: Tap water 4).

Three treatment groups comprising three replicates from each treatment group and the control were set up in tanks with nine circular plastic tanks of the same size in each tank setup. These tanks were cleaned with diluted (Raw wastewater 1: Tap water 4) apparel industrial wastewater (Nizam *et al.*, 2020; Ullah *et al.*, 2022). Diluted wastewater in plastic tanks with a 10 L capacity was divided into three treatment groups, each of which had three replicas, keeping the control tanks of wastewater free of plants.

E. Transferring and storing aquatic plants to the prepared tanks

25 g of plants from each species were utilized to treat a 10 L sample of diluted wastewater from each tank. Three replicates of each of the acclimatized plants were transplanted to the tanks. Three replicates of each species were made to get an average reading to guarantee a predictable trend of pollution reduction. No additional effluent was added to the tanks at any stage during the experiment (Nizam *et al.*, 2020). The set-up was created so that the plants were allowed to cooperate with natural processes and receive enough aeration and sunlight (Mokhtar *et al.*, 2018; Kafle *et al.*, 2022). To observe the development of the plant's effects on the wastewater, information and observations from each day were collected (Mokhtar, *et al.*, 2018).

F. Sampling of wastewater

Initial sampling

On the day the experimental setup was assembled, wastewater samples from each tank were collected using 250 mL sample bottles as the initial sampling. Sample bottles and caps were rinsed with sample water. Following sampling, the bottle cap was taped shut and labelled. Triplicate analyses of each parameter were performed. Heavy metals were determined in each tank after wastewater samples were collected using the grab sampling technique and 250 mL sample bottles every three days for 18 days.

Before being used for testing, samples were stored at a cold (4 °C) temperature (Wickramasinghe and Jayawardana, 2018).

A Varian AA240FS Atomic Absorption Spectrometer was used to determine heavy metals in the samples. Before analysis, 50 mL of wastewater samples were filtered through 25 mm Syringe Filters (Nylon membrane, 0.22 m) and digested with 5 mL of concentrated Nitric acid (HNO₃) (APHA, 2005-Section 3030E). The acidified and filtered materials were analyzed to determine heavy metals including Cd, Cu, and Zn in the Varian model AA240FS Flame Atomic Absorption Spectrophotometer user manual.

Sampling of wastewater over time

Investigations of the development of the plant's effects on the wastewater were conducted using observations from each day (Moktar, *et al.*, 2018). After transferring the plants, wastewater samples were collected in sample bottles and analyzed for heavy metals every three days for the 18 days of the experiment.

G. Determination of percentage reductions of heavy metals

Following 18 days, the effluent heavy metals concentration percentage reductions were calculated using the equation 1;

$$\text{Percentage Reductions} = \frac{I_0 - I_1}{I_0} \times 100 \dots (1)$$

I₀ – Initial concentration,

I₁ – Concentration at the end of the experiment

H. Data and statistical analysis

Descriptive statistics were used to illustrate how the wastewater quality fluctuated over time in the treatment and control tanks.

The mean effluent concentrations and reduction percentages for the various treatments and control groups were compared after 18 days using one-way ANOVA. The software packages Minitab[®]17 and MS Excel 2016 were used to examine the data.

3. RESULTS AND DISCUSSION

A. Reduction efficiencies of Cd

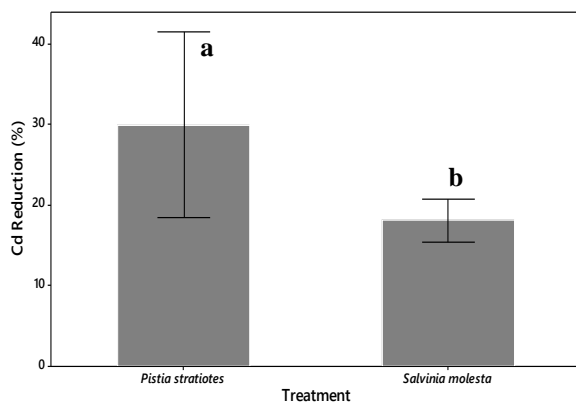
Initial Cd content of the wastewater was 0.78±0.0058 mg/L. Figure 1 shows the average Cd levels after an 18-day period in tanks treated with plants. At the end of the experiment, Cd concentrations were recorded in tanks treated with *S. molesta*, *P. stratiotes* and control tanks as 0.63±0.0038 mg/L, 0.55±0.0382 mg/L, and 0.81±0.0414 mg/L respectively. Table 1 shows the Cd variation (mg/ L) during the experiment.

Table 1: Cd variation (mg/ L) during the experiment

Day	<i>S. molesta</i>	<i>P. stratiotes</i>	Control
Initial day	0.77±0.0085	0.78±0.0035	0.78±0.0167
Day 3	0.76±0.0084	0.77±0.0067	0.81±0.0650
Day 6	0.73±0.0056	0.74±0.0050	0.81±0.0081
Day 9	0.75±0.0066	0.72±0.0191	0.88±0.0618
Day 12	0.72±0.0046	0.67±0.0344	0.88±0.0289
Day 15	0.67±0.0140	0.66±0.0131	0.79±0.0682
Day 18	0.63±0.0038	0.55±0.0382	0.81±0.0414

(Values in the table are mean ± SD of 3 replicates)

At the end of the experiment, a reduction of Cd was not recorded in control tanks. After 18 days, there was a substantial (p < 0.05) reduction in the average Cd values measured in the control tanks and the plant-filled tanks. Compared to other days, 0.66±0.0131 mg/L of Cd concentration in wastewater recorded on the 15th day was reduced to 0.55±0.0382 mg/L at the end of the 18th day by the tanks treated with *P. stratiotes*. The *P. stratiotes* tank showed the highest Cd reduction efficiency of the investigated plant species (29.97%), whereas *S. molesta* showed a reduction efficiency of 18.13%. According to the findings from this study, *P. stratiotes* exhibited greater Cd reduction when exposed to wastewater from the apparel industry.



Individual standard deviations were used to calculate the intervals.

Figure 1: Average percentage reductions of Cd after 18 days

Because it is very poisonous and easily absorbed from the environment by organisms, Cd is a non-essential element that can enter the food chain through wastewater (Balamoorthy *et al.*, 2022). As the availability of this metal is highly dependent on the pH, the retention of Cd in contaminated water bodies requires special care (Mulligan *et al.* 2001). In the research conducted by Wickramasinghe and Jayawardana (2018), the tank treated with *P. stratiotes* showed the maximum Cd reduction (47.4%), whereas *S. molesta* showed a reduction efficiency of 36.8%. The present study also indicated a higher Cd percentage reduction in the tank treated with *P. stratiotes* in comparison to *S. molesta*. According to Donatus (2016), before treatment Cd concentration was 0.251 mg/L while it was 0.018 mg/L after treatment with *Salvinia molesta* on industrial wastewater. In the pH range of 0 to 9, Cd^{2+} is soluble; however, above this point, Cd is present in the form of oxides, which are either little or no soluble at all (Schwantes *et al.*, 2015).

B. Reduction efficiencies of Cu

Cu was initially present in industrial wastewater at a concentration of 0.56 ± 0.0153 mg/L. At the end of the experiment, Cu concentrations were recorded in tanks treated with *S. molesta*, *P. stratiotes* and control tanks as 0.27 ± 0.0159 mg/L, 0.32 ± 0.0320 mg/L, and 0.75 ± 0.1716 mg/L respectively. At the end of the experiment, a Cu reduction was not recorded in

control tanks. Cu level of the tanks treated with *S. molesta* was 0.51 ± 0.0245 mg/L on the 3rd day and 0.27 ± 0.0159 mg/L at the end of the experiment (day 18th).

Table 2 shows the Cu variation (mg/ L) during the experiment.

Table 2: Cu variation (mg/ L) during the experiment

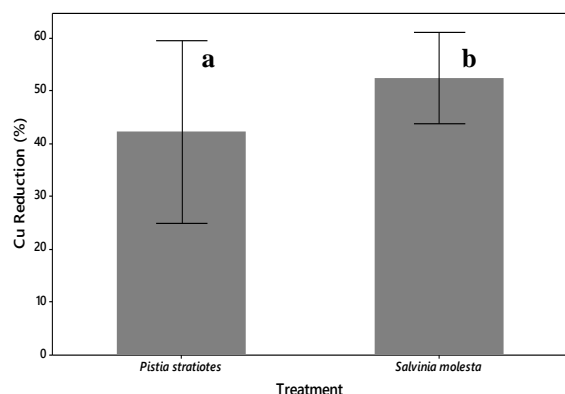
Day	<i>S. molesta</i>	<i>P. stratiotes</i>	Control
Initial day	0.57 ± 0.0081	0.56 ± 0.0218	0.59 ± 0.0125
Day 3	0.51 ± 0.0245	0.53 ± 0.0119	0.55 ± 0.0290
Day 6	0.49 ± 0.0225	0.49 ± 0.0191	0.57 ± 0.0470
Day 9	0.43 ± 0.0159	0.44 ± 0.0196	0.59 ± 0.0497
Day 12	0.38 ± 0.0603	0.43 ± 0.0393	0.68 ± 0.0341
Day 15	0.32 ± 0.0250	0.34 ± 0.0079	0.64 ± 0.0457
Day 18	0.27 ± 0.0159	0.32 ± 0.0320	0.75 ± 0.1716

(Values in the table are mean \pm SD of 3 replicates)

Compared to the 3rd day during the experiment, 0.53 ± 0.0119 mg/L of Cu concentration in wastewater was decreased to 0.32 ± 0.0320 mg/L at the end of the 18th day by the tanks treated with *P. stratiotes*. The efficacy of *S. molesta* in the removal of Cu from wastewater was improved by 52.47 % while it was 42.37 % for *P. stratiotes*. Therefore, according to the obtained results, as represented in Figure 2, higher Cu reduction efficiency was recorded by *S. molesta* in comparison to *P. stratiotes*.

According to the study by Miretzky, Saralegui and Cirelli (2004), Cu removal percentages were 97.3 %, 72.2 % and 73.5 % for *P. stratiotes* when adding Cu concentration was 1, 2 and 4 mg/ L. In the study Manjunath and Kousar (2016), tanks treated with *P. stratiotes* and *S. molesta* recorded 100% reduction of Cu in 25% and 50% concentration of the effluent percentage. In that study, before the phytoremediation, the Cu concentration in effluent was negligible and it

was zero after the treatment with *P. stratiotes* and *S. molesta*.



Individual standard deviations were used to calculate the intervals.

Figure 2: Average percentage reductions of Cu after 18 days

According to Donatus (2016), before treatment Cu concentration was 1.092 mg/L while it was 2.035 mg/L after treatment with *Salvinia molesta* on industrial wastewater.

The findings of Fia *et al.* (2015) study indicated, total suspended particle removal is linked to the primary mechanism of Cu removal, which they claim can vary with pH. They observed a removal of Cu from 91% to 98% in their study. Cu have been diluted and redistributed to new plants after the development of the plants. Additionally, it is permitted for the plant to introduce the element into the system, which can result in the creation of poorly soluble Cu complexes in alkaline pH conditions (Schwantes *et al.*, 2015).

C. Reduction efficiencies of Zn

The wastewater's initial Zn concentration was 0.43 ± 0.0058 mg/L. At the end of the experiment, Zn concentrations were recorded in tanks treated with *S. molesta*, *P. stratiotes* and control tanks as 0.34 ± 0.0010 mg/L, 0.36 ± 0.0062 mg/L, and 0.40 ± 0.0037 mg/L respectively. There was no Zn reduction was recorded in control tanks at the end of the experiment, therefore, figure 3 shows the average Zn percentage reductions following an 18-day trial in tanks treated with plants. At the end of the experiment, 22.89 % Zn removal efficiency was recorded by *S. molesta* while it was 17.87 % for *P. stratiotes*.

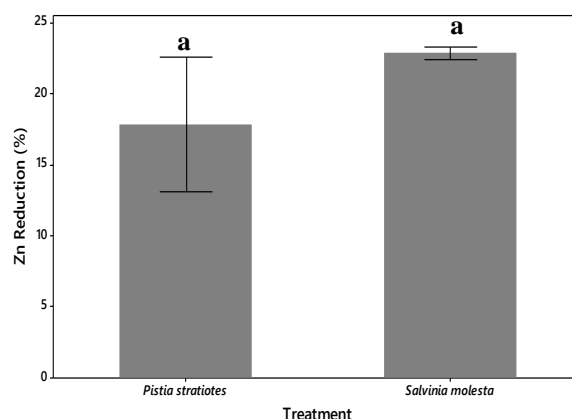
Table 3 shows the Zn variation (mg/ L) during the experiment.

Table 3: Zn variation (mg/ L) during the experiment

Day	<i>S. molesta</i>	<i>P. stratiotes</i>	Control
Initial day	0.44 ± 0.0004	0.43 ± 0.0052	0.43 ± 0.0024
Day 3	0.41 ± 0.0014	0.38 ± 0.0024	0.42 ± 0.0093
Day 6	0.40 ± 0.0120	0.37 ± 0.0007	0.40 ± 0.0013
Day 9	0.37 ± 0.0066	0.36 ± 0.0086	0.46 ± 0.0060
Day 12	0.44 ± 0.0008	0.32 ± 0.0044	0.39 ± 0.0056
Day 15	0.42 ± 0.0023	0.44 ± 0.0070	0.40 ± 0.0025
Day 18	0.34 ± 0.0010	0.36 ± 0.0062	0.40 ± 0.0037

(Values in the table are mean \pm SD of 3 replicates)

After 18 days, as Figure 3, there was no noticeable difference between the average Zn values measured in the control tanks and the tanks containing plants ($p > 0.05$). Based on the obtained results of the present study, higher absorption of Zn was recorded by *S. molesta* from apparel industrial wastewater.



Individual standard deviations were used to calculate the intervals.

Figure 3: Average percentage reductions of Zn after 18 days

Zinc is necessary for the growth of plants and the stimulation of enzymes involved in photosynthesis (Moktar and Tajuddin, 2019). According to Fia *et al.* 2015, Zn removal ranges from 51% to 99% depending on the total suspended solids' direct removal ratio. This metal also tends to be less soluble when the pH is close to neutrality. In 2012, according to the study conducted by Matos *et al.*, (2012) achieved 88% Zn removal efficiency. Zn was removed by 70% and 55%, respectively, when Módenes, *et al.*, (2009) examined the removal of Zn at various temperatures (30 °C and 50 °C). Zn precipitation according to pH fluctuation was confirmed by Módenes *et al.*, (2009), who also confirmed that the precipitation process starts when the pH rises over 5.50. According to the study by Schwantes *et al.*, 2015, aquatic plants' senescence may have caused Zn to be released into the environment. Zn may have precipitated such as $ZnOH^+$, ZnO , and $Zn(OH)_2$, though, as *P. stratiotes* discharged the metal into the media. There was no reduction of heavy metals recorded in control tanks during the experiment.

The findings of the current study showed that two plant species are efficient in removing heavy metals (Cd, Zn, and Cu) from apparel industrial wastewater media throughout an 18-day trial period. Among these, absorption of Cu was higher than that of the other two metals. The efficiency of removal was in this order $Cu > Zn > Cd$ for *S. molesta* while it was $Cu > Cd > Zn$ for *P. stratiotes*.

Rhizofiltration, phytostabilization, phytodegradation, phytoextraction, and phytovolatilization are a few of the techniques that plants utilize to clean up contaminated soil and water that are included in phytoremediation (Fletcher *et al.*, 2020; Balamoorthy *et al.*, 2022; Kafle *et al.*, 2022). Rhizofiltration, which refers to the removal of contaminants from aqueous medium by a plant's root system, can be used to indicate how the chosen plant kinds remove metals from wastewater (Lakshmi *et al.*, 2017; Wani *et al.*, 2017; Wickramasinghe and Jayawardana, 2018; Fletcher *et al.*, 2020; Kafle *et al.*, 2022).

The accumulation and distribution of heavy metals in plants is influenced by variety of factors including plant species, root region, environmental factors, root

composition and component species, and soil physio-chemical and biological characteristics (Lakshmi *et al.*, 2017). Balamoorthy *et al.*, (2022) stated that heavy metals are absorbed and excreted by plants via translocation and absorption processes. The presence of plants and their uptake during in the photosynthetic process for plant growth during the experimental period are related to the reduction of heavy metals (Moktar and Tajuddin, 2019). Balamoorthy *et al.*, (2022) stated that, due to the fact that the initial contact of plants with the toxins occurred on its own, the rhizomes of the plant are considerable to the phytoremediation process. According to studies, Nizam *at el.*, (2020) and Sa'at and Zaman (2017), the leaves and roots of *S. molesta* are very effective at capturing and removing pollutants, particularly heavy metals. Findings of Roy, Jahan and Rahman (2018), indicated that the heavy metals were being biomagnified by *Eichhornia*, *Spirodela*, and *Pistia stratiotes* by collecting them in their bodies and root systems.

The present study showed that these plants take up contaminants and store them as biomass, showing a high tolerance for contaminants like heavy metals and an ability to absorb large amounts of them. The overall results demonstrate that *S. molesta* and *P. stratiotes* can be used as effective and efficient phytoremediation agents to remove heavy metals in low-concentration apparel industrial wastewater for 18 days.

4. CONCLUSION

The results of this investigation suggest that *S. molesta* and *P. stratiotes* are effective at eliminating heavy metals from wastewater used in the apparel industry. Several conventional methods are being used to remediate the contaminants in the apparel wastewater. They consist of reverse osmosis solvent extraction, electrolysis, chemical oxidation, ion exchange, coagulation, chemical precipitation, and ultra-filtration (Ekanayake and Manage, 2020). However, a lot of these techniques are pricey, and some of them result in a lot of sludge. In this present study, heavy metals and other toxins from apparel effluent were removed using a phytoremediation approach that included floating aquatic plants. *S. molesta* was more effective than *P.*

stratiotes at removing Cu, Cd, and Zn, with removal efficiencies of 52.47%, 18.13%, and 22.89%, respectively. *S. molesta* was shown to be a better accumulator of Cu and Zn than Cd, according to the study's findings. As compared to Zn, it was found that *P. stratiotes* was a superior accumulator of Cu and Cd. After going through the phytoremediation process, the treated plant material can be safely burned away, and the accumulated metals can be recovered for use in industry. The current analysis is consistent with the numerous phytoremediation studies conducted on *Salvinia molesta* and *Pistia stratiotes* demonstrating that those plants are effective heavy metal accumulators and can be employed in apparel industrial wastewater phytoremediation.

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DEGRADATION OF MALACHITE GREEN USING GREEN SYNTHESIZED IRON NANOPARTICLES BY *Coffea arabica* LEAF EXTRACTS AND ITS ANTIBACTERIAL ACTIVITY

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ABSTRACT

The synthesis of biocompatible nanomaterials using bio-renewable plant extract has emerged as a promising alternative to traditional methods in recent years due to its cost-effectiveness, eco-friendliness, non-toxicity, and biocompatibility. In this research paper, we demonstrate using *Coffea arabica* leaf extract to synthesize zero-valent iron nanoparticles (GC-FeNPs). This study suggests that this method is efficient and environmentally friendly, making it a promising approach for developing biocompatible nanomaterials. The synthesized GC-FeNPs were characterized using Fourier-Transform Infrared (FT-IR), X-ray diffraction (XRD), scanning electron microscope (SEM), and UV-Vis spectroscopy techniques. According to the analysis of data, polyphenolic/caffeine compounds in the coffee leaf extract act as reducing/capping agents by converting the Fe^{2+} to Fe^0 , and minimizing the aggregation. The FT-IR and XRD data confirm the encapsulation of the GC-FeNPs by the polyphenolic/caffeine compounds in the coffee leaf extract. The GC-FeNPs have a quasi-spherical shape morphology with a particle size of about 80 – 100 nm. Further, dye degrading ability, and the antibacterial activity of the GC-FeNPs were investigated using malachite green (MG) and gram-negative and gram-positive pathogens. Experimental data revealed that GC-FeNPs ($\sim 20 \pm 1$ mg) showed degradation activity against MG up to 55 % upon the 120-minute incubation. Furthermore, the kinetic analysis of GC-FeNPs on MG degradation was in accordance with the pseudo-second-order kinetic model ($R^2 = 0.9922$). In addition, GC-FeNPs showed an antibacterial activity against gram-negative (*E. coli*, and *S. enterica*), and gram-positive (*S. aureus*) pathogens. The *E. coli* growth was highly inhibited by the GC-FeNPs compared to other strains. Overall, GC-FeNPs facilitate an alternative approach to degrade MG from textile effluents and industrial wastewater and treat the pathogen-contaminated water.

KEYWORDS: Green synthesis, Iron nanoparticles, *C. arabica*, Malachite green, Degradation, Antibacterial activity

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1. INTRODUCTION

Water is an essential element on the earth, and numerous living organisms rely on it. However, water quality is degrading consistently due to various contaminations. Dyes play a significant role in water contamination all over the world. Annually, 700,000 tons of synthetic dyes are used worldwide for the dyeing operation process; around 15 -20 % end up in wastewater and find their way to the environment (Basturk and Karatas, 2015). Dye is a very harmful compound to the environment and living organisms due to its reactivity (Leme *et al.*, 2015; Xiao *et al.*, 2020). Aquatic plants are highly affected due to dye contamination in water since dye colour promotes turbidity (Khandare and Govindwar, 2015; Verma and Samanta, 2018). Turbidity in water bodies reduces the penetration of the sun's rays into the water body and affects photosynthesis.

Further, the biotransformation of the dyes into different products poses various threats to living organisms and the environment. However, due to the photo and heat stability, most dyes do not degrade quickly in the environment (Basturk and Karatas, 2015). Therefore, for the past few decades, novel techniques have been developed to treat wastewater contaminated by dyes. Also, degradation by techniques such as physicochemical adsorption (Gao, Si and He, 2015), electrocoagulation (Kobyia *et al.*, 2014), membrane filtration (Chidambaram, Oren and Noel, 2015), nano-filtration (Paździor *et al.*, 2009), ozonation (Panda and Mathews, 2014), Fenton oxidation, and oxidation processes were identified as good strategies (Soares *et al.*, 2015). However, the formation of toxic compounds may reduce the effectiveness of these methods. Therefore, biodegradation of the dye has been employed using aerobic and anaerobic bacteria (Popli and Patel, 2015), Sequencing Batch Reactor (SBR) (Santos and Boaventura, 2015), *etc.* These biological processes were further found to be effective to a certain extent but challenging to sustain in dye-contaminated wastewater.

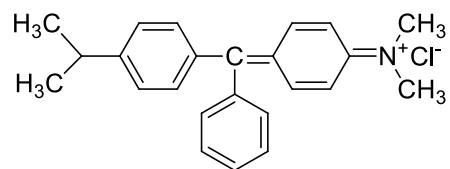


Figure 1: Chemical structure of the malachite green

Malachite green (MG) is a cationic triphenylmethane (Figure 1) dye used in the dyeing process in different industries such as fabrics, paint, inks, leather, *etc.* (Huang *et al.*, 2014a; Xiao *et al.*, 2020). It is vital to remove MG from wastewater before discharging into the environment due to its toxicity. Therefore, different methods such as the adsorption (Gao, Si and He, 2015), biological degradation (Tsai, and Chen, 2010; Yatome *et al.*, 1993), and photocatalytic degradation (Wu *et al.*, 1999; Hachem *et al.*, 2001; Elango and Roopan, 2015), are employed to remove MG content in the wastewater. However, due to the drawbacks such as high cost and low efficiency associated with these techniques, the applicability in the degradation process of MG is limited to a certain extent. Therefore, novel remediation techniques as an alternative are required to remove MG in wastewater effectively.

Recently, nano zero-valent iron (nZVI) has attracted research interest in groundwater treatment due to the higher intrinsic reactivity of its surface sites (Iravani, 2011; Dutta *et al.*, 2016). Numerous chemical and physical approaches have been deployed for the synthesis of nZVI. However, these physical methods are associated with drawbacks such as energy consumption, expensiveness, the requirement of sophisticated laboratories, *etc.* (Sun *et al.*, 2006; Nadagouda *et al.*, 2010; Huang *et al.*, 2014b). Sodium borohydride (NaBH_4) is commonly used as a reducing agent in the chemical synthesis of nZVI (Devatha, Thalla and Katte, 2016). However, reducing agents such as NaBH_4 , stabilizing agents, capping agents, and organic solvents in chemical synthesis are limited due to the expense and toxic effect on the environment (Sun *et al.*, 2006;

Nadagouda *et al.*, 2010; Huang *et al.*, 2014b). The green synthesis of nZVI has been identified as an alternative approach due to its cost-effectiveness, eco-friendliness, biodegradability, and non-toxicity. Green synthesis received much attention due to the usage of bio-renewable natural sources (Tandon, Shukla and Singh, 2013; Huang *et al.*, 2014a; Wang, Fang and Megharaj, 2014; Das and Eun, 2018). Recently, various nanomaterials have been synthesized using different green extracts (Njagi *et al.*, 2011; Mohan Kumar *et al.*, 2013; Zhu *et al.*, 2018). Generally, components such as polyphenols available in tea and coffee extract have emerged as an alternative for the chemical synthesis of nZVI since they can act as both a reducing and capping agent (Mohan Kumar *et al.*, 2013; Ouyang *et al.*, 2019). This feature of the green extract reduces the aggregation and the oxidation of the nZVI particles (Chen *et al.*, 2011). The green synthesis of nZVI using green extract polyphenols has been investigated for biocompatibility, degrading bromothymol blue by the Fenton oxidation process (Shahwan *et al.*, 2011), and degradation of the trichloroethylene (TCE) by developing Fe/Pd membrane using a green tea extract (Smuleac *et al.*, 2011). Fenton-like catalytic properties of the green synthesized iron nanoparticles (FeNPs) have been investigated for the degradation of dyes. The reactivity of the green synthesized FeNPs is significantly dependent on the reducing and capping agents of the green extract. Various green extracts promote different reactivities of the green synthesized FeNPs, (Raveendran, Fu and Wallen, 2003; Makarov *et al.*, 2014). The FeNPs synthesized using green extracts have been employed for dye adsorption and eutrophication remediation (Lin *et al.*, 2017).

Researchers have recently used tea extracts to synthesize iron nanoparticles for the selective removal of MG from wastewater. (Huang *et al.*, 2014a, 2014b; Xiao *et al.*, 2020). In 2014, Huang's group (Huang *et al.*, 2014a) conducted a similar study utilizing FeNPs synthesized using tea extracts. The results indicated that the removal efficiency of MG was 81.6%, with an equilibrium

at around 60 minutes. The rate kinetics were better fitted to the pseudo-first-order model ($R^2 = 0.925$). The experiment was conducted using 0.01 g/L of nanomaterial, which was incubated with an 8 mL 50-ppm solution of MG. A recent study by Xiao's group (Xiao *et al.*, 2020) reported that FeNPs synthesized using green methods could effectively remove MG from wastewater. The researchers reported a degradation efficiency of 95.14% for MG, with an equilibrium achieved at approximately 100 minutes. The rate kinetics of the process were found to be better described by the pseudo-first-order model, with an R^2 value of 0.95. The study was conducted by utilizing 0.01 g of nanomaterial incubated in a 50-ppm solution of MG. The observed deviations in batch experiment analysis may be attributed to the variations in experimental conditions and the quantity and composition of polyphenolic compounds used for encapsulating iron nanomaterials. The specific experimental conditions, such as temperature, pressure, and pH level, as well as the type and concentration of polyphenolic compounds in the plant extracts used for the synthesis process, could impact the physicochemical properties of the iron nanoparticles. These physicochemical properties, in turn, may influence the behaviour and performance of the nanoparticles in the batch experiment analysis, resulting in deviations. This study aims to synthesize FeNPs from *Coffea arabica* leaf extract and characterize the FeNPs using SEM, FT-IR, UV-Vis, and XRD analysis. The reactivity of FeNPs in malachite green degradation and antibacterial activity against gram-positive and gram-negative bacteria were also evaluated. To the best of our knowledge, this is the first study that reports on the antibacterial and degradation effect of malachite green in the presence of green synthesized FeNPs using *Coffea arabica* leaf extract.

2. METHODOLOGY

A. Materials

Ferrous sulfate heptahydrate (99%, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) was purchased from Sigma Aldrich, and malachite green (MG) was purchased from DYECHEM

(Colombo, Sri Lanka). *Coffea arabica* (coffee) leaves were collected from local farms. Muller Hinton Agar from Hi-Media Laboratories and deionized (DI) water was used in all experiments.

B. Preparation of leaf extract

Fresh coffee leaves were collected from a local farm and washed thoroughly with DI water to clean the leaf's surface. Leaves were dried at room temperature. Twenty-five grams of dry leaves of *C. arabica* were cut into small pieces and mixed with 150.0 mL of deionized water (Figure 2). The temperature of the solution was maintained at 60 °C and kept on stirring for 1 hour. The resulting solution was allowed to cool to room temperature and filtered using gravity filtration. The green extract was stored at -4 °C for further use.

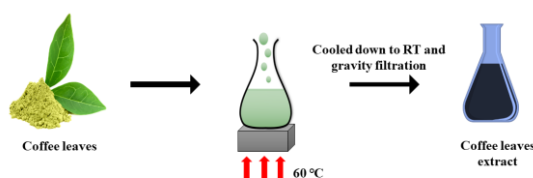


Figure 2: Preparation of the coffee extract

C. Green synthesis of iron particles

Coffee FeNPs (GC-FeNPs) were synthesized, as shown in Figure 3. The coffee leaf extract was added to 0.10 M FeSO_4 solution with a volume ratio of 1:1 at room temperature and continuously stirred at 75 °C for 1 hr. The immediate colour change to black colour indicated the formation of GC-FeNPs. As synthesized GC-FeNPs were separated using gravity filtration. The product was washed three times with ethanol to remove the remaining residues of the coffee leaf extract and dried using a vacuum oven at 25 °C for 24 hrs.

D. Characterization

The synthesized nanomaterials were characterized using UV-Vis, FT-IR, SEM, and XRD techniques.

1. UV-Vis spectroscopy

The absorption spectra of GC-FeNPs treated solutions were analyzed using UV-Visible

spectrophotometer (ChromTech, CT-2600, Taiwan).

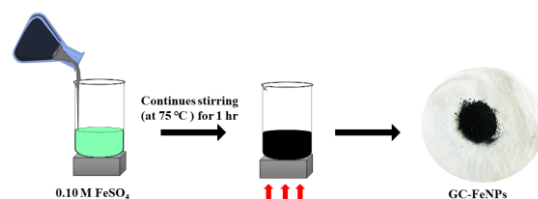


Figure 3: Preparation of the GC-FeNPs

2. Fourier transform infrared spectroscopy (FT-IR)

Fourier Transform Infrared Spectroscopy (FT-IR) analysis of GC-FeNPs was done over the range of 4000 - 400 cm^{-1} to investigate the fabrication of GC-FeNPs by the coffee leaf extract. The measurements were performed on a FT-IR spectrometer (Bruker Vertex80 FT-IR spectrometer, Germany).

3. Scanning electron microscopy (SEM)

The microstructure and size of the GC-FeNPs were characterized using scanning electron microscopy (Carl Zeiss Evo 18 Research, Germany). SEM images of the sample were obtained at different magnifications using an operating voltage of 20 kV.

4. X-ray diffraction (XRD)

The crystallinity state of GC-FeNPs was analyzed by X-ray diffraction (Rigaku SmartLab X-Ray Powder Diffractometer, Japan) using with Cu-K β radiation source at room temperature. It was operated at 40Kv/30mA over 2θ range of 5 to 80°. The scanning speed was maintained at 10 min^{-1} .

E. Degradation of malachite green – Batch experiment

The removal efficiency of MG was evaluated using GC-FeNPs; 100 μL suspension of GC-FeNPs was ($\sim 20 \pm 1$ mg) added to a solution containing 100 ppm MG (25.0 mL). Then, the conical flasks were placed in a rotary shaker at 298 K and 150 r/min. After a decided specific time, the degraded solutions were taken out and filtered through Whatman No. one filter paper to remove the GC-FeNPs. The resulting solution was

analyzed to determine the remaining concentration of MG. A calibration plot of absorbance vs concentration for the MG was prepared using a standard series to evaluate the MG concentration of the degraded solution. According to the UV-Vis spectroscopy the maximum wavelength (λ_{max}) for the MG was identified as 617 nm. Hence, the absorbance of the degraded MG solution was measured using a UV-Spectrophotometer at 617 nm. The removal efficiency (η) and the amount of absorbed dye per unit mass of sorbent at a given time (q_t , mg/g) and equilibrium (q_e , mg/g) using GC-FeNPs were calculated by using the following equations (Wang and Li, 2013; Katata-Seru *et al.*, 2018; Gao *et al.*, 2019):

$$\eta = \frac{C_0 - C_t}{C_0} \times 100 \% \quad (1)$$

$$q_t = (C_0 - C_t)V/W \quad (2)$$

$$q_e = (C_0 - C_e)V/W \quad (3)$$

Where η = the MG removal efficiency, C_0 = the initial MG concentration in the solution (ppm), C_t = the MG concentration at a time (ppm), and C_e = the MG concentration at the equilibrium (ppm). All experiments were undertaken in triplicate, and the error values are not very significant.

F. Antibacterial activity studies

The antibacterial activities of green synthesized GC-FeNPs and antibiotic compound streptomycin were evaluated against gram-negative *Escherichia coli* (*E. coli* ATCC 25922), *Salmonella enterica* ATCC 14028, and gram-positive *Staphylococcus aureus* ATCC 25923 by disk diffusion method using Muller Hinton agar (MHA) medium (Prakash *et al.*, 2013; Elango and Roopan, 2015). Briefly, microbes were grown on nutrient agar at 37 °C for 24 hrs. Afterward, fresh nutrient agar was inoculated with the overnight culture and incubated until the optical density at 600 nm (OD_{600}) reached 0.5. Then, the bacterial suspensions were spread on the MHA plates using a sterile spreader. Sterile Whatman No. one paper discs at 6 mm dimension were impregnated with coffee leaf extract and GC-FeNPs. The disc with

streptomycin antibiotic compound was used as the positive control reference. These discs were gently pressed in MHA plates and incubated in an inverted position at 37 °C for 24 hrs to determine the Zone of inhibition. All experiments were undertaken in duplicate.

3. RESULTS AND DISCUSSION

A. FT-IR analysis

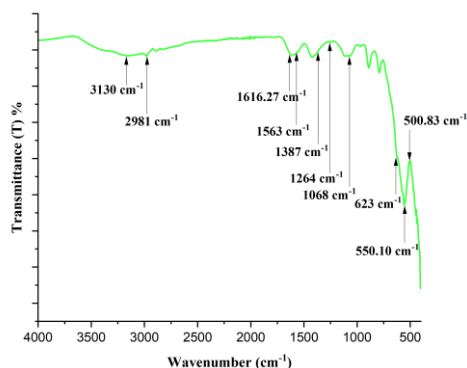


Figure 4: FT-IR spectra of the GC-FeNPs

The FT-IR analysis identified different functional groups in the synthesized GC-FeNPs (Figure 4). FT-IR spectra showed eight significant peaks in the 400-1700 cm^{-1} range. Several studies have reported that different functional groups were responsible for green GC-FeNPs synthesis (Shahwan *et al.*, 2011; Akhbari *et al.*, 2019). According to the FT-IR spectra, stretching vibrational bands at 2981 cm^{-1} , 1068 cm^{-1} , and 3129.54 cm^{-1} , correspond to stretching vibrations of C-H, C-O-C, and OH bonds (Lopez *et al.*, 2010; Wang *et al.*, 2014; T. *et al.*, 2020; Xiao *et al.*, 2020; Parthipan *et al.*, 2021). The peaks at 1616 cm^{-1} and 1387 cm^{-1} attribute for C-N of aromatic amines (Lopez *et al.*, 2010; Wang *et al.*, 2014; T. *et al.*, 2020; Xiao *et al.*, 2020; Parthipan *et al.*, 2021). The absorption band at 1563 cm^{-1} is related to the conjugated system of benzene (Lopez *et al.*, 2010; Wang *et al.*, 2014; T. *et al.*, 2020; Xiao *et al.*, 2020; Parthipan *et al.*, 2021), which confirms the functionalization of the GC-FeNPs by the polyphenols/caffeine compounds in the coffee leaf extract. Furthermore, peaks at 550.10 cm^{-1} and 500.83 cm^{-1} correspond to the Fe-O vibrational

stretches, which confirms the formation FeNPs using coffee extract as a reducing and capping agent (Lopez *et al.*, 2010; Wang *et al.*, 2014; T. *et al.*, 2020; Xiao *et al.*, 2020; Parthipan *et al.*, 2021).

B. SEM analysis

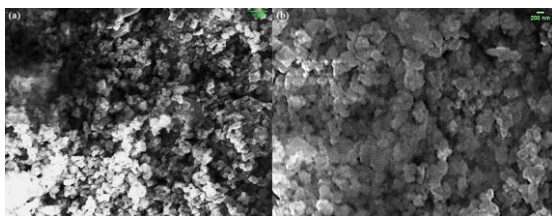


Figure 5: SEM images of the GC-FeNPs (a) 15 KX and (b) 25 KX magnification

The morphologies and size of GC-FeNPs were determined by SEM, as shown in Figure 5, which indicated the successful synthesis of iron nanoparticles. SEM images of GC-FeNPs revealed that the morphology of the iron particles is in quasi-spherical shaped nanoparticles with a diameter ranging from 80 - 100 nm (Smuleac *et al.*, 2011). Further, many GC-FeNPs form irregular clusters consistent with the previously reported green synthesized iron-based nanoparticles (Njagi *et al.*, 2011; Shahwan *et al.*, 2011). The size distribution of the GC-FeNPs mainly occurs due to the reducing properties associated with natural compounds in the coffee green extract. Also, these compounds act as a capping agent and a stabilizer to avoid the oxidation of the zero-valent iron particles (α -Fe⁰) when exposed to the air. (Wang *et al.*, 2014)

C. XRD analysis

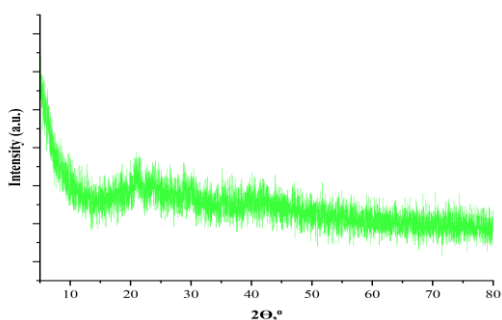


Figure 6: XRD pattern of the GC-FeNPs

The X-ray diffractometer analysis was explored to identify the crystalline nature of the synthesized GC-FeNPs (Figure 6). The XRD pattern shows that the GC-FeNPs are an amorphous structure. The α -Fe⁰ surface has been encapsulated by coffee leaf extract polyphenols/caffeine, which function as a dispersive and capping agent in the synthesis process, as confirmed by the FT-IR analysis of the GC-FeNPs. The broad shoulder peak at 21.43° is determined to be the absorption peak of polyphenols/caffeine in the coffee extract (Njagi *et al.*, 2011; Cao *et al.*, 2016). The broad peak around 45° on the G_nZVI corresponds to the α -Fe⁰ (Huang *et al.*, 2014a; Wang *et al.*, 2014; Dutta *et al.*, 2016; Katata-Seru *et al.*, 2018; Xiao *et al.*, 2020).

D. Degradation of malachite green and kinetic studies

1. Degradation of Malachite Green (MG)

Figure 7(a) illustrates the degradation of the MG using the GC-FeNPs at different periods. The characteristic absorption peak of MG, which is attributed to the -C=C- functional group, is located at 617 nm. (Wang *et al.*, 2017; Xiao *et al.*, 2020) As decolorization occurs, the peak at 617 nm decreases with time due to the reactivity of GC-FeNPs. This signifies the remarkable potential of GC-FeNPs in degrading MG from the aqueous system by cleaving the -C=C- bond of the MG. (Wang *et al.*, 2017; Xiao *et al.*, 2020) According to Figure 7 (a), the initial concentration of the MG 100 ppm was reduced to 64.9 ppm after 20 min of incubation with the GC-FeNPs. Then, the MG concentration gradually decreased, and the MG concentration at equilibrium was 45 ppm. According to Figure 7(b), degradation efficiency reached 51 % at 40 min, and degradation efficiency reached 55 % at 120 min. These data indicate valuable insights for the development of more effective and sustainable methods for the removal of MG from aqueous systems.

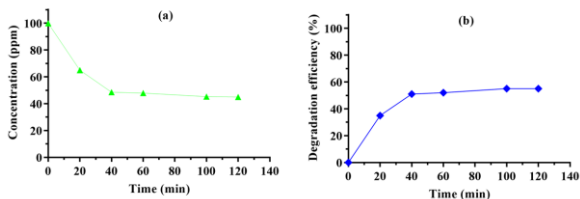


Figure 7: (a) Variation of the MG concentration with time upon the GC-FeNPs incubation, (b) MG degradation efficiency with time upon the GC-FeNPs incubation

2. Kinetic Studies

The adsorption kinetics of the MG onto adsorbent (GC-FeNPs) were investigated using pseudo-first-order and pseudo-second-order equations. These models are highly dependent on adsorbent material's physical and chemical characteristics. The pseudo-first-order is more suitable for lower concentrations of the solution, and the pseudo-first-order rate equation can be expressed as follows (Wang *et al.*, 2014; Gao *et al.*, 2019):

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (4)$$

Where q_e and q_t (mg/g) are the amounts of MG molecules adsorbed on the GC-FeNPs at equilibrium and at different times t (min^{-1}) and k_1 is the rate constant of the pseudo-first-order model for the adsorption process (min^{-1}). The linear plot of $\ln(q_e - q_t)$ against time, as shown in Figure 8(a), was used to calculate the rate constant k_1 . The slope of the linear plot gives the value for the k_1 .

The pseudo-second-order kinetic model equation is expressed as follows (Bhattacharyya and Gupta, 2008; Gao *et al.*, 2019):

$$\frac{dq_t}{dt} = k_2 (q_e - q_t)^2 \quad (5)$$

Integrating Eq. (5) by applying the boundary conditions $t = 0$ to t and $q_t = 0$ to t , gives:

$$\frac{1}{(q_e - q_t)} = \frac{1}{q_e} + k t \quad (6)$$

When Eq. (6) linearized, it expressed as follows:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \left(\frac{1}{q_e}\right) t \quad (7)$$

Where, q_e and q_t (mg/g) are the amounts of MG molecules adsorbed on the GC-FeNPs at equilibrium and at different times t (min^{-1}) and k_2 ($\text{g mg}^{-1} \text{min}^{-1}$) is the rate constant of the pseudo-second-order model for the adsorption process. Values of the k_2 and q_e can be determined from the plot of t/q_t against t , as shown in Figure 8(b).

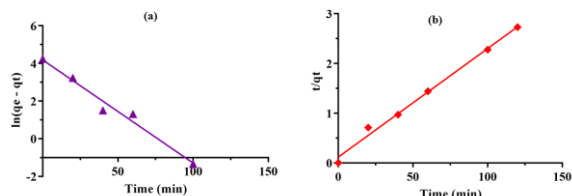


Figure 8: (a) Pseudo-first-order kinetics of GC-FeNPs and (b) pseudo-second-order kinetics of the GC-FeNPs

Table 1. The kinetic parameters of MG degradation by GC-FeNPs

Dye type	Pseudo First Order		Pseudo Second Order	
	K_1 (min^{-1})	R_1^2	K_2 ($\text{g mg}^{-1} \text{min}^{-1}$)	R_2^2
MG (100 ppm)	0.0548	0.9760	0.0040	0.9922

The correlation coefficients (R^2) show that MG adsorption onto the GC-FeNPs was better fitted for the pseudo-second-order ($R^2 = 0.9922$) compared to the pseudo-first-order model, according to Table 1. Therefore, the adsorption of MG onto GC-FeNPs did not follow the pseudo-first-order model but well-fitted the pseudo-second-order model.

E. Antibacterial activity

The antibacterial activity of the GC-FeNPs was evaluated using the gram-negative *Escherichia coli* (*E. coli* ATCC 25922), *Salmonella enterica* ATCC 14028, and gram-positive *Staphylococcus aureus* ATCC 25923 by disk diffusion assay (Figure 9).

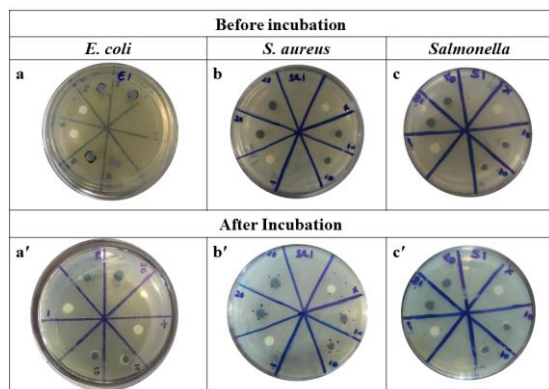


Figure 9: Zone of inhibition (a) *E. coli*, (b) *S. aureus* and (c) *Salmonella*

The inhibitory activity of the synthesized GC-FeNPs (10 μL and 20 μL) with varying concentrations against the tested isolates was tested. The Pathogens' Zone of inhibition (DIZ)

values ranged from 0.6 to 1.1 cm, as indicated in Figure 9. This study used various control groups such as coffee leaf extract, positive control (streptomycin), and distilled water, to inhibit pathogens.

Table 2. Zone of inhibition obtain in antibacterial activity

Concentration (μL)	<i>E. coli</i> (cm)	<i>S. aureus</i> (cm)	<i>Salmonella</i> (cm)
10	0.9 ± 0.1	0.9 ± 0.0	0.6 ± 0.0
20	1.1 ± 0.1	1.0 ± 0.0	0.8 ± 0.0

According to the study, GC-FeNPs exhibited a predominant role against pathogenic bacteria such as *E. coli* (10 μL – 0.9 cm, 20 μL – 1.1 cm) and *S. aureus* (10 μL – 0.9 cm, 20 μL – 1.0 cm) compared to the *Salmonella* (10 μL – 0.6 cm, 20 μL – 0.8 cm) as shown in Table 2. The positive nature of GC-FeNPs could promote antibacterial activity due to the interactions with the cellular membrane of gram-negative and gram-positive pathogens by disrupting the cell membrane and producing reactive oxygen species (Hu *et al.*, 2019; Sadek, Asker and Abdelhamid, 2021).

However, the coffee leaf extract shows no antibacterial activity against the bacterial strains selected in this study.

4. CONCLUSION

In this study, the green synthesis of FeNPs was carried out with *Coffea arabica* leaf extract, and FT-IR, XRD, and SEM analysis confirmed the formation of GC-FeNPs. The polyphenols/caffeine in the coffee leaf extract acted as a reducing and capping agent that reduced the aggregation of the GC-FeNPs. The FT-IR analysis confirms the functionalization of GC-FeNPs by the polyphenolic/caffeine compounds in the coffee leaf extract. Also, XRD data confirm the availability of $\alpha\text{-Fe}^0$ and encapsulation of GC-FeNPs by the polyphenolic/caffeine. At the same time, the SEM analysis shows that the synthesized GC-FeNPs have a quasi-spherical shape morphology with a particle size of about 80 – 100 nm. The green synthesized GC-FeNPs can be utilized in environmental applications such as the toxic dye MG degradation process. The experimental data confirmed that the GC-FeNPs could effectively degrade the 100 ppm MG in an aqueous solution by using a 100 μL suspension ($\sim 20 \pm 1$ mg) of GC-FeNPs compared to the previously reported MG degradation using nanomaterials synthesized using different plant extracts. The MG degradation efficiency by GC-FeNPs reached 45 ppm (55 % degradation efficiency) with an equilibrium around 120 minutes. The kinetic study of the MG degradation revealed that the degradation of MG by GC-FeNPs is well-fitted with the pseudo-second-order adsorption model ($R^2 = 0.9922$). In addition, the GC-FeNPs showed potential antibacterial activity against *E. coli* and *S. aureus* compared to *Salmonella*. The antibacterial activity of the GC-FeNPs increased with higher concentration, and the growth of *E. coli* strain was highly inhibited by the GC-FeNPs. Therefore, GC-FeNPs can be explored as a promising nanomaterial for treating contaminated water sources, particularly for removing toxic dyes.

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AN INVESTIGATION OF FACTORS AFFECTING EMPLOYABILITY OF BIG DATA PROFESSIONALS IN SRI LANKA; WITH SPECIAL REFERENCE TO LOGISTIC COMPANIES

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ABSTRACT

Big Data Analytics is swiftly growing and has revolutionized the field of business, through advanced analytics. Similarly, Sri Lanka is progressively embracing big data technology and the pioneering adopters include logistics companies. This emerging field has opened up many employment opportunities for big data professionals (BDP). However, Sri Lanka has encountered a shortage of BDP, amidst the significant growth in the field. Thus, this study analyze the factors that potentially impact the employability of BDP in the field of big data analytics, with the motive of finding solutions to reduce the skill shortage, which serves as the main objective of the research. The study was executed by analyzing qualitative and quantitative data collected through a questionnaire survey followed by a series of structured interviews. The questionnaire survey was distributed among 180 employees who are currently employed in the field of big data analytics, whereas, the structured interviews were carried out with 08 experts in the field. Based on the initial Exploratory Factor Analysis conducted, Education Factors, Skills and Competencies, and Job Market Factors were identified as the three main variables which affect the employability of BDP. Subsequently, a Thematic Analysis was carried out in order to investigate the impact of the aforementioned factors on the big data skill shortage, and to navigate possible remedies for it. Based on the data analysis conducted and results derived, it was depicted that the employability of BDP is directly related to Education Factors, Skills and Competencies and Job Market factors. As implications of the study it was revealed that certain educational and competency development factors should be enhanced in order to diminish the skill shortage of BDP.

KEYWORDS: *Big Data Professionals, Demand, Skill shortage, Employability*

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1. INTRODUCTION

Background of the study

In the present context, data has taken a new stance called “Big Data”. It is a pool of data that is massive in volume yet growing exponentially with time. LIRNE Asia, (2017) placed the development of Sri Lanka in the spotlight of big data, stressing the importance of up-to-date and accurate data, for a developing economy. The study relates to the field of logistics, in order to explore the shortage of BDP. This is mainly because it is one of the pioneering adopters of big data technology.

Figure 1 illustrates the latest statistics by World Economic Forum, regarding the technology utilization in the field of transportation and logistics. Big data analytics is ranked first among all the other technology enabled infrastructure, showcasing the potential of the field of logistics.

Figure 2 shows the investment on Big Data in the field of logistics. It distinguishes the forecasted increase in investments within the upcoming five-year period, showing the potential impact of Big Data on the field of logistics.

This study becomes unique and exclusive since it strives to investigate an aspect which has not grabbed significant attention from previous researchers. It is

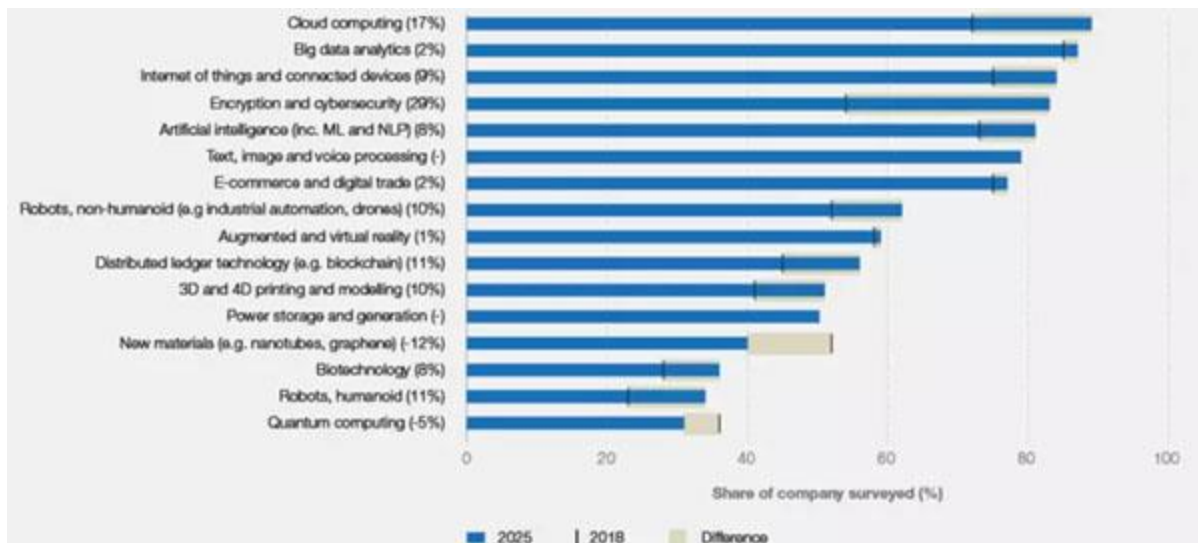


Figure 1: Technology Adoption in the field of logistics and transportation

Source: World Economic Forum. (2020)

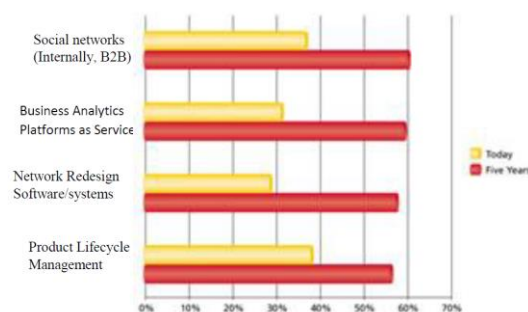


Figure 2: Existing and planned investment capacities for Big Data technologies Source: BVL International, 2013

a highly technical field from the human perspective, by emphasizing the importance of human resources to carry out big data analytics. At the onset, the research study intends to scrutinize the reasons for the shortage of big data skill locally and globally. Initially, the study anticipates determining the most influential factors that affect the employability of BDP, through an Exploratory Factor Analysis.

Even though there is an increasing demand for BDP, Sri Lanka has encountered a shortage of supply of professionals to cater to this growing demand. World

Economic Forum (2019), Part (2010), Phillips (2017), and Rae (2018) examined that the job market has encountered a shortage of BDP. Therefore, the study strives to resolve the query, “What factors would affect the employability of BDP and what remedies could be undertaken to reduce the shortage of professionals, to reach the true potential of big data analytics?”

Literature Review

Ohlhorst 2013 expressed that big data is undertaken by many companies in the world as a main source of competitive advantage.

Even though the demand for BDP is rapidly increasing, the job market has indicated a significant gap in BDP, implying that the supply of professionals to the job market is poor, even though they are of high demand.

There is forecasted gap in-between supply and demand of BDP in US, for the year 2018. Based on that, the projected demand is much higher than the forecasted supply, resulting in a shortage in big data skill of 50%-60%.

Big data analytics is the scarcest skill in the global corporate field. As shown in the Figure 2.4, the market size of big data is expected to grow at a rapid rate.

Economy	Current DSA Workers	Projected DSA Workers Needed	Percent Change
Malaysia ²⁴	4,000 (2016)	20,000 (2020)	400%
The Philippines ²⁵	147,420 (2016)	340,880 (2022)	131%
Singapore ²⁶	9,300 (2015)	15,000 (2018)	61%
Canada ²⁷	33,600 (2016)	43,300 (2020)	33%
United States ²⁸	2,350,000 (2015)	2,720,000 (2020)	16%

Figure 3: Expected growth of Big Data Market from 2011 to 2027 Source: Columbus, (2017)

Right human skill is critical in big data analytics (Dubey, et al., 2019; Wamba, et al., 2017). According

to SHRM, 2016, 59% of organizations expect to elevate the job positions, which require the skill of data analysis, from 2017-2021.

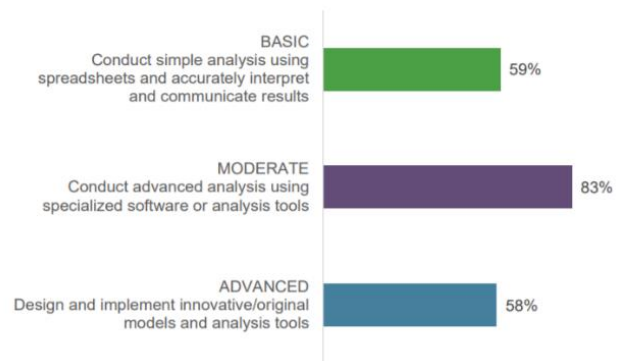


Figure 4: Demand of different skill levels for BDP Source: SHRM, (2016)

Figure 4 interprets different skill levels required by employees. The analysis revealed that 60% of the organizations demand BDP with the ability to interpret and communicate results.

Table 1: Time duration of Undergraduate and Postgraduate Big Data related programs in Sri Lankan public and private Universities Sources: IIT (2020), NSBM (2020), SLIIT (2020), UOM (2019), USSC (2020)

Type	Name of the University/Institution	Academic program	Time Duration
Public	University of Moratuwa	Postgraduate certificate in data analysis and pattern recognition	1 year
	University of Colombo School of Computing (USSC)	Master of Business Analytics	2 years
Private	Informatics Institute of Technology (IIT)	BSc(Hons) Artificial Intelligence and Data Science	4 years
	Sri Lanka Institute of Information Technology (SLIIT)	BSc (Hons) in Information Technology Specializing in Data Science	4 years
	National Institute of Business Management (NIBM)	BSc (Hons) Data Science	3 years
	National Institute of Business Management (NIBM)	Advanced Diploma in Data Science	1 year
	NSBM Green University Town	Professional Diploma in Data Science	1 year

Education and subject related knowledge are core

factors anticipated by employers, when recruiting BDP. DASCA (2020) is a pioneering credentialing body for the data science profession. SAS (2020) is an international institute which offers certification to BDP, which is a value addition for them in career progression.

Time duration of higher educational qualifications play a significant role, since it gives a gist of the quality and capacity of the specific qualification.

The time durations of local undergraduate and postgraduate programmes relating to big data and advanced analytics are indicated in Table 1. This illustrates the duration of some selected degree and masters programmes that are related to big data and advanced analytics.

International educational platforms for big data analytics such as Pearson and Lytics Labs facilitate mainstream physical or virtual learning of various modules (Williamson, 2017).

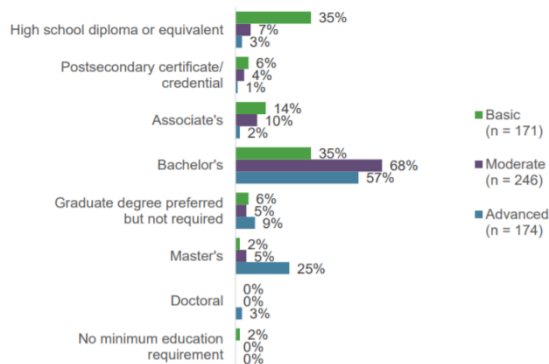


Figure 5: Educational Requirement at each level of recruitment
Source: SHRM, (2016)

Figure 5 is a breakdown of big data workforce, according to their educational qualifications.

IBM Data Science Professional Certificate is a platform which offers a vivid range of courses for professional BDP, which can be pursued independently even while engaging in employment

(Widjaja, 2019). Oxford and Harvard Universities offer short term professional courses for BDP (Dhawan & Zanini, 2014).

However, the study of Ajah & Nweke, (2019) revealed that many organizations are not sufficiently equipped with knowledge and skill to implement big data analytics or to interpret the results of it. Therefore, it suggested the importance of building an organizational culture oriented on analytics, by bridging this skill and knowledge gap. Based on this, Harvey Nash/ KPMG CIO, (2020) revealed that 35% of the employers are anticipating to transform the workforce to polish their technology-related competencies.

DSA Framework Category	Postings Requesting Experienced Workers (at least 3 Years Prior Work Experience)
All	81%
Data-Driven Decision Makers	88%*
Functional Analysts	71%
Data Systems Developers	84%
Data Analysts	76%
Data Scientists & Advanced Analysts	78%
Analytics Managers	94%*

Figure 6: Workforce entry by prior experience
Source: Columbus, (2017)

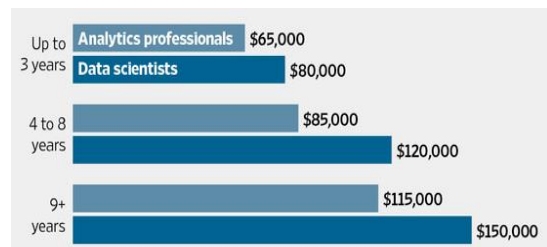


Figure 7: Salary of BDP with the experience level
Source: Waller, (2014)

According to the Figure 6, more than 76% of employers anticipate recruiting experienced BDP. The study of Park City Math Institute, (2016) stated that “Capstone projects” should be a mandatory component of the experience and internship programmes for Big Data employees,

Based on the Figure 7, as the experience grows, the remuneration of the big data employees increase.

Blake (2019) claimed that the field of data science is a very gratifying career which is increasingly relied upon by the society.

Aryal, et al. (2018), Cao (2017), Columbus (2017), and Wamba, et al. (2019) showed that embracing of big data technology in organizations require high level software like Hadoop, Apache pig and database management systems –NoSQL.

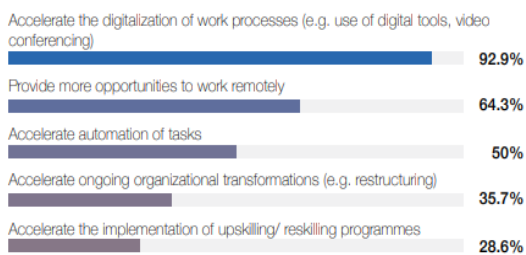
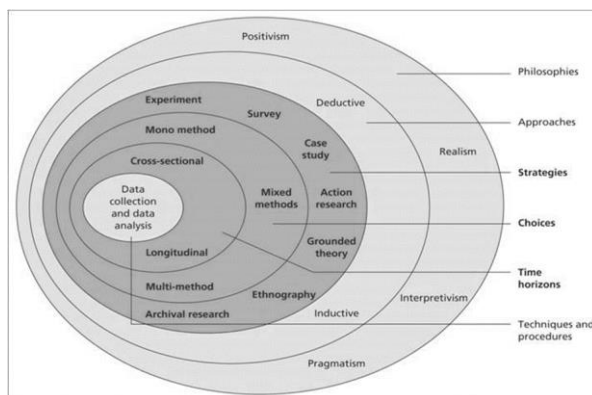


Figure 8: Impact of COVID-19 pandemic on logistics and transportation companies
Source: World Economic Forum , (2020)

Figure 8 is a representation of different strategies that global logistics companies follow to adopt to the “New Normal”, post COVID-19.

2. METHODOLOGY



3. Figure 9: Research Onion Source: Saunders et al. (2009)

The research onion (Figure 9) which was developed

by Saunders et al. (2009) explains the stages to be followed when developing a research strategy.

This study is conducted based on Pragmatism. Vallack (2010) explained that this philosophy is ideally used for research studies conducted based on a mixed method.

An inductive approach is selected based on the layout and execution of the research study.

The study involves the use of structured interviews and questionnaire surveys as its research strategies to collect qualitative and quantitative data. Thus, this study adopts a mixed method approach. Further, the study uses a cross sectional approach, where the information is gathered at a particular point of time.

Population

The target population for the series of structured interviews is the experts in the field of Big Data, and the respondents for the questionnaire survey are employees of selected logistic companies.

Sample

In order to collect data for the questionnaire survey, sample size of 180 operational and management level respondents in the field of technology were requested to fill in a questionnaire. The sample size was determined by the Morgan & Krejcie (1970) table, based on the method of simple random sampling under probability sampling. Structured interviews were conducted with selected Industry experts in the field of Big Data, and the sample size was decided by locating the saturation point after investigating the responses.

Exploratory Factor Analysis

This research is a very unique study and it explores an area which was not overlooked by many prior researchers. Thus, the researchers lacked firm theory and substantial models to support the conceptual framework in order to develop a hypothesis.

Therefore, an Exploratory Factor Analysis was conducted at the beginning, in order to determine the factors which affected the employment of BDP.

Determining the factors

The researchers initially determined certain indicators, that would possibly be affecting the employment of professionals in the field of big data analytics. Those indicators were chosen randomly, based on the literature survey. The aforementioned indicators include Competency of employees, Academic Knowledge, Higher Educational Qualifications, Remuneration, Experience, Soft Skills, Managerial Skills, Orientation of Qualifications, Professional Qualifications, Existing professionals in the field, Recognition, Infrastructure, Accreditations, Professional Networks and Time Duration

Data Collection

Based on the indicators identified by the researchers, a questionnaire was developed and circulated and the researchers considered the responses of 180 operational and managerial level employees, in order to conduct the Exploratory Factor Analysis.

Preparation of data for analysis

Removing outliers

Based on the data collected, there were four potential outliers, and they were excluded from the dataset as shown in the Table 2.

Table 2: Data Screening
Source: Sample Survey (2020)

Questionnaire responses collected	180
Questionnaires discarded	26
Questionnaires considered	154
Outliers Removed	04
Questionnaires utilized	150

Table3: Guidelines for KMO Values

Source: Hutcheson & Sofroniou, (1999)

Indicator	Value
Poor	<0.5
Average	0.5 – 0.6
Acceptable	0.6 – 0.7
Good	0.7 - 0.8
Excellent	>0.8

Table4: KMO Bartlett’s Test Source:

Sample Survey (2020)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.693
Bartlett's Test of Sphericity	Approx. Chi-Square	502.064
	Df	78
	Sig.	.000

According to Table 4, outputs indicate that KMO sampling adequacy value is 0.693 which is considered as an acceptable value, according to Hutcheson & Sofroniou (1999). The matrix can be ruled out if the Sig. value of the test is less than 0.005 (Field, 2000; Pallant, 2013). Therefore, since the sig. value in Bartlett's Test of Sphericity is less than 0.005, the data set is adequately sampled.

Principle Component Analysis

A Principle Component Analysis (PCA) was conducted in order to distinguish the factors affecting employment of BDP. According to the initial analysis conducted, Higher Educational Qualifications, Academic Knowledge and Remuneration were identified as three doubtful indicators. This was because, their communality value was below 0.3 and the value in the component matrix was less than 0.5. If the communality value is less than 0.3, then it means that only less than 30% of the variance in this indicator shares a common origin with others. Therefore, those indicators should be excluded from the analysis (Hadi, et al., 2016). The component matrix displays the factor loadings without rotating the variables. If it contains any indicator less than 0.5, then the impact of that indicator to that specific variable is considered to be negligible.

After filtering those three indicators, the same Principal Component Test was carried out. Then the researchers considered the output of the “Total Variance Explained” in Table 4.4.

Table 5: Total Variance Explained
Source: Sample Survey (2020)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.953	24.607	24.607	2.953	24.607	24.607	2.471	20.595	20.595
2	2.357	19.641	44.248	2.357	19.641	44.248	2.174	18.120	38.715
3	1.344	11.198	55.447	1.344	11.198	55.447	2.008	16.732	55.447
4	1.077	8.972	64.419						
5	.879	7.328	71.748						
6	.722	6.016	77.763						
7	.664	5.535	83.298						
8	.563	4.689	87.988						
9	.453	3.771	91.759						
10	.372	3.101	94.860						
11	.335	2.792	97.652						
12	.282	2.348	100.000						

Extraction Method: Principal Component Analysis.

variables could be determined by clustering all the indicators into three main categories. However, the fourth indicator also showed a value greater than one. Therefore, a parallel analysis was conducted in order to verify the total number of variables.

The parallel analysis in the Table 6 shows how the number of variables were determined to carry out factor extractions. In this process, the Eigenvalues obtained from PCA are compared with the Eigenvalues generated by Patil et al. (2017). The two values are compared in a way that if the Eigenvalue generated from PCA is greater than that of the parallel analysis, then the indicator is accepted (Horn, 1965).

After determining the number of independent variables for factor extractions, then the factors are rotated for further analysis. The main motive behind factor rotation is to align them in a way which makes it more convenient for interpretations.

Based on the Rotated Component Matrix in Table 7, the researchers loaded the factors to three main variables. The factor loadings were done so that the factors with a value more than 0.5 are grouped into categories based on their orientation.

The researchers labelled the factors based on the composition of indicators in them. This was based to develop the conceptual framework for the study.

Normality

Table 9 shows the normality measures of the data set of the research study.

Rose et al. (2015) mentioned that if the standard error of skewness and Kurtosis are within the range of +1.96 and -1.96, then the data set is normal. Since the

Table 6: Parallel Analysis
(Source: Sample Survey 2020)

Component Number	Eigenvalue from the PCA	Parallel Analysis Value	Final Decision
1	2.953	1.519	Accept
2	2.357	1.386	Accept
3	1.344	1.281	Accept
4	1.077	1.192	Reject

Table 5 revealed that 55.47% of the total variances were achieved from the first three factors collectively. It indicated that 03 independent

standard errors of the data set shown in Table 4.8, are in between this range, and it can be concluded that it is normal.

Table 7: Rotated Component Matrix (Source: Sample Survey 2020)

	Component		
	1	2	3
Existing professionals	.786		.185
Recognition in the local job market compared to foreign job market	.756		
Adoption of new infrastructure	.686		.118
Effect of industry experience	.643		
Professional networks	.596		
Presence of sufficient local qualifications		.827	.230
Crash courses to be completed in less time		.804	.204
Accreditation body provide guidance	.131	.636	.215
Professional qualifications		.611	-.126
Effect of business and managerial skills		.130	.827
Satisfaction level of local graduates compared to foreign graduates			.801
Effect of soft skills		.148	.691

Table 8: Labelling Factors Source: Sample Survey (2020)

Factors	Labelled Factors	Indicators	Factor Loadings
01	Job Market Factors	Existing Professionals	.786
		Recognition	.756
		Infrastructure	.686
		Experience	.643
		Professional Networks	.596
02	Educational Factors	Orientation of Qualifications	.827
		Time Duration	.804
		Accreditations	.636
		Professional Qualifications	.611
03	Skills and Competencies	Managerial Skills	.827
		Competency of Graduates	.801
		Soft Skills	.691

Table 9: Skewness and Kurtosis (Source: Sample Survey -2020)

	Education Factors	Skills and Competencies	Job Market Factors
Skewness	-.187	-.613	-.403
Std. Error of Skewness	.198	.198	.198
Kurtosis	-.208	.119	-.267
Std. Error of Kurtosis	.394	.394	.394

Testing for Validity and Reliability

The researchers utilized Expert Validity technique, since the relationship between variables are yet unknown until the Exploratory Factor Analysis is conducted.

Reliability test was done by getting the Cronbach's alpha value in SPSS. Bernstein (1994) confirmed that the standard value for Cronbach's alpha could be more than 0.6, which was previously recommended by Bagozzi R.P. (1988). The Table 4.9 represents the reliability values of each variable utilized in this research study along with the number of indicators in each variable.

Table 10: Reliability for each variable (Source: Sample Survey -2020)

Variable	Cronbach's Alpha	No of items
Educational Factors	.715	4
Skills and Competencies	.620	4
Job Market Factors	.718	6
Employment	.644	3

Testing for Multicollinearity

Table 11: Multicollinearity
(Source: Sample Survey -2020)

	Tolerance	VIF
Education Factors	.961	1.040
Skills and Competencies	.994	1.007
Job Market Factors	.899	1.112

If the tolerance value of the variables exceeds “one”, then there is no multicollinearity between the variables. However, if this value equals to “zero”, then the variables show perfect multicollinearity. Therefore, based on the Table 2.10, the variables considered in the study are proven to have no multicollinearity. The acceptable range of VIF value is between 10 and 0.1 (Field, 2005). The variables of the study abide by this rule as well. Hence, it shows that there is no multicollinearity prevailing among the variables.

Descriptive Statistics
Demographic profile

The 150 respondents were categorized into five groups under different age levels as 18-25, 26-35, 36-45, 46-55, 56 and above. Among them, the age group between 26-35 represented the majority (44%) of respondents. Significantly, there are no responses recorded from 56 and above age category. This gives an indication of the novelty of the field of big data. It shows the increased attention and attraction towards the field by younger generation when compared to older generation. Since only a very few respondents above the age of 46 have responded to the questionnaire, it could be assumed that the field of big data is not much embraced by the employees belonging to that age limit (Figure 10).

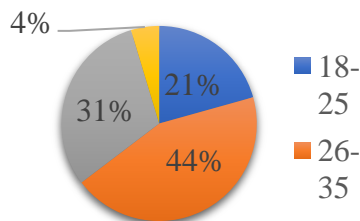


Figure 10: Age (Source: Sample Survey -2020)

When considering about the Highest level of education, only 7% of the respondents belonged to the category of PhD. The highest percentage of respondents are in the group who have completed their Bachelor’s Degree (55%). As Figure 11 demonstrates, all the respondents have acquired more qualifications than Advanced Level.

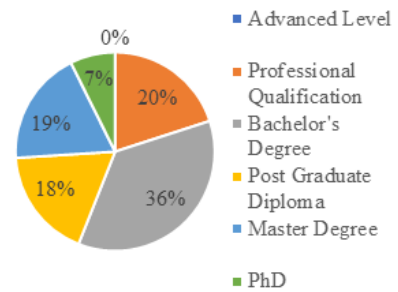


Figure 11: Highest Educational Qualification
Source: Sample Survey (2020)

Researchers further analyzed whether the respondents have acquired their highest educational qualifications from a local or a foreign University/institution. Among the 150 respondents, majority have acquired their highest educational qualification from foreign Universities/institutions, and it amounts to 52%. There are 48% employees who have acquired their highest educational qualification locally, which is comparatively lesser than graduates from foreign Universities. This demarcates the lack of higher educational platforms for BDP locally. The Figure 12 shows the orientation of the educational qualifications of respondents, based on the country and region.

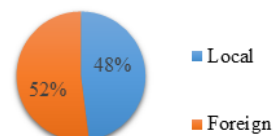


Figure 12: Local/Foreign Qualifications
Source: Sample Survey (2020)

Based on the Figure 13, majority of the respondents were data analysts, which summed up to a percentage

of 33.22%. Both data scientists and data warehouse managers represented 17.11% each, which were the second highest. Meanwhile, the respondents include only a very less number of database managers.

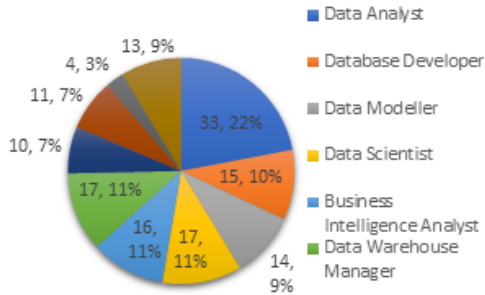


Figure 13: Job Profile
Source: Sample Survey (2020)

In order to analyze the most commonly utilized software in Sri Lanka, five main types of software which are commonly used by BDP are considered and the respondents rated them based on their level of utilization. According to the Figure 14, most professionals heavily utilize Apache Spark, while Hadoop is ranked second based on high usage. Meanwhile, Hadoop and Apache spark are utilized mostly in the moderate usage category as well. Cassandra, R and Tableau are rated as low usage software by the respondents.

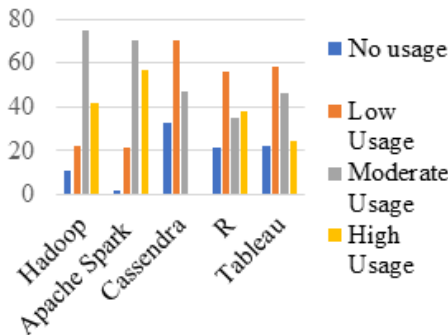


Figure 14: Infrastructure Usage
Source: Sample Survey (2020)

Researchers intended to analyze the impact of the COVID-19 pandemic to the big data employees. Based on their responses, most companies have initiated teleworking platforms due to the “New Normal” culture in the business sector. This was

mentioned by 47% of the respondents, which summed up to be the highest. 36% of the employees have mentioned that they have been introduced with flexible working hours. 13% of the respondents have commented that all the traditional big data related platforms were transferred to the cloud. Based on the Figure 15, only a few number of employees experienced salary cut downs. This implies that COVID-19 has very slightly impacted the field in a negative manner.

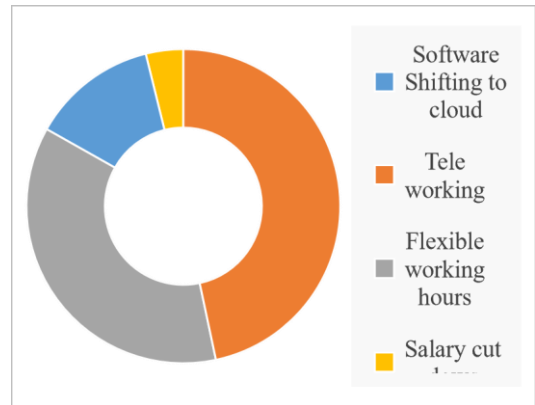


Figure 15: Impact of COVID-19
Source: Sample Survey (2020)

Thematic Analysis

The research study employs thematic analysis to review and analyze qualitative data collected through a series of structured questionnaires.

Initial Reading of Texts

Braun & Clarke (2012) explained that this initial step is very vital to understand the content and the basic idea derived from various aspects.

Coding the Texts after Repeated Reading

In this phase, researchers generated 108 basic codes after the comprehensive analysis of the responses.

Generating Themes through Codes

The concept behind the generation of themes is the process of consolidation of the codes into like groups (Attride-Stirling, 2001; Braun & Clarke, 2006;

Lincoln & Guba, 1985). The final result obtained by the researchers included three main themes called Educational Factors, Skills and Competencies and Job Market Factors. Apart from that, another two codes; namely, Importance of Big Data in Logistics and Impact of COVID-19 on the field, were separately considered by the researchers, based on their significance to the field.

Presentation of data was in such a way that the researcher coded initially along with the themes generated through them.

Thematic Network

The thematic network shown in Figure 16 was developed by the researchers by investigating the codes developed through the interview texts.



Figure 16: Thematic Network
Source: Sample Survey (2020)

Data Analysis

The data analysis is conducted by analyzing the themes and codes generated by the researcher.

Importance of Big Data in the field of Logistics

All the respondents agree that big data is perfectly compatible with the field of logistics. They placed the value of big data for the field of logistics in the “High” category, since it is a unique yet a valuable integration of two fields.

Educational Factors Accreditations

Many have agreed that there are no recognized accreditation bodies locally. However, 63% of the respondents have commented that there are ample recognized accreditation bodies for big data professionals globally. Adding to this, Respondent eight has stated that there are recognized accreditation bodies for BDP, such as DASCA, IOA and CAP by Informis.

Time Duration

Half of the respondents commented that there are crash courses for BDP. Justifying this, Respondent seven has said that there are online platforms like Coursera. Meanwhile, respondent eight has also said that there are online crash courses offered by IBM and Google. Conversely, the remaining 50% of the respondents have commented that there are no crash courses for the employees in the field of big data analytics.

Orientation of Qualifications

Respondent five and six have commented that the standard of local graduates who get graduated from local Universities is high when compared to foreign graduates. However, majority of the respondents have stated that the quality and standard of foreign qualifications are high when compared to local qualifications.

Professional Qualifications

Three Respondents have commented that

professional qualifications are scarce in the local context. Majority of the respondents have agreed that there are ample professional qualifications available for BDP internationally. Respondent one has mentioned Udemy and Coursera as examples, in order to justify her point of view. Respondent two, three and six have commonly mentioned AWS as a recognized professional qualification. Respondent seven has given multiple examples such as Cloudera, Hortonworks, Elasticsearch, AWS, Azure, Cloud, Datadog and Snowflakes.

Skills and Competencies

Soft Skills

All the respondents have commonly expressed that soft skills are very important for BDP. They have specifically said that Communication is the most important skill, since it enables the professionals to express their findings to the top management and to the clients.

Managerial Skills

Majority of the respondents have agreed that managerial skills are critical for BDP. Justifying this, many respondents have collectively stated that people handling, time management, cost management, critical thinking and project management skills are vital for BDP. However, the respondents four, seven and eight have mentioned that it is not very critical for big data employees to possess managerial skills, since they engage in a technical role rather than in a managerial role.

Competency of Graduates

Four respondents have stated that many companies implement ample competency development programmes for employees in the field of big data. Respondent seven has interestingly mentioned that even though his company extends training and development programmes for BDP, they mostly expect the employees to be self-taught. Respondents one, four and six mentioned that there are only a smaller number of competency development

programmes for BDP in local companies and they only cater to the specific requirements of employees. Also, Respondent six has stated that the company he is employed in has newly initiated training and development programmes for BDP. However, respondent two has strongly mentioned that there are no competency development programmes for BDP as at now.

Job Market Factors

Experience

All the respondents have commonly agreed that level of experience is a major factor affecting the employment of BDP. Respondents one and five have mentioned the importance of experience to drive performance and career progression of an employee.

Recognition

The researchers identified that the opinion of the majority of the respondents was that big data analytics as a profession is not yet recognized in Sri Lanka. According to Respondents one, three, four, five and seven, the field is still in the emerging stage, which is the main cause for the lack of recognition. Respondent two has captivately mentioned big data analytics as a “Surprise Field”.

Existing Professionals

Based on the responses received, respondents one, six and seven have mentioned that the number of existing professionals in the field locally are very less. Meanwhile, respondent two has mentioned that the existing professionals have so much to improve when compared to foreign professionals.

Infrastructure

Majority of the respondents have stated that most companies in Sri Lanka constantly update their infrastructure related to big data analytics. Respondent six has stated that their company conducts a lot of research on latest developments of infrastructure. However, respondent three has given

a contrary opinion saying that local companies do not regularly update their infrastructure.

Professional Networks

All the respondents have commented that professional networks are of utmost importance to the employees in the field of big data.

3. DISCUSSION

The conceptual framework (Figure 3.2) was developed by the researchers, based on the Exploratory Factor Analysis conducted at the onset of the research study. The relationship and correlation between the Independent Variables and the Dependent Variable was revealed through that, and this model was developed as an outcome of the same.

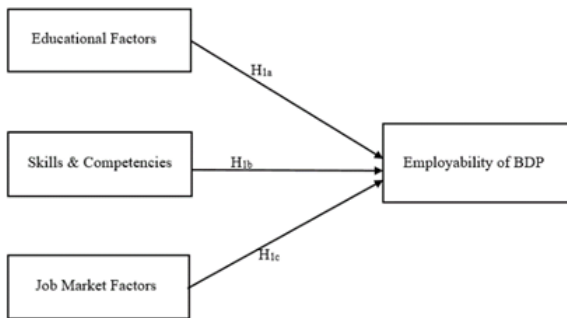


Figure 17: Conceptual Framework
Source: Developed by the researcher

Considering this, three main hypotheses were developed.

H_{1a} – Educational Factors impact the Employability of BDP

H_{1b} –Skills and Competencies impact the Employability of BDP.

H_{1c} –Job Market Factors impact the Employability of BDP.

The outcomes of both the Exploratory Factor Analysis and the Thematic Analysis displayed a significant similarity in spite of the slight differences between responses.

H_{1a}: Educational Factors impact the Employability of BDP

DASCA, 2020; the standards body ensures that all its accredited institutions are hiring destinations that are preferred by most organizations. Thus, accreditations of local and foreign bodies have a high impact on the employability of BDP.

Based on the research findings, there are many contemporary crash courses in big data analytics as well; namely, Coursera, 2020; EDX, 2020.

Even though there is only a less number of local qualifications on big data analytics, there are many foreign qualifications. SAS in collaboration with Birmingham City University has launched a programme called SAS Student Academy. Many local BDP declare that there are not much recognized higher educational platforms for big data analytics in Sri Lanka, which has to become a major concern in order to increase the number of professionals in the job market.

The experts in the field of big data mention that platforms such as AWS, 2020 facilitate professional education. Majority of the respondents have stated that they constantly feel the need of a standard professional qualification when working in a corporate setting, in order to update their knowledge and to climb up the corporate ladder. However, a concern is raised on the lack of professional qualifications locally, which might be an influential factor contributing to the current big data skill shortage.

H_{1b}: Skills and Competencies impact the Employment of BDP

Interactive disciplines of Big Data Analysts should embrace soft skills such as critical thinking, creative thinking and communication (Song, 2016). All the respondents of the questionnaire survey commented that soft skills are of utmost importance to big data employees as well.

SAS, The Tech partnership, 2014 specified that the employers are interested in potential BDP with interpersonal, management and business insights. Majority of the respondents, along with a majority of the interviewers have agreed that managerial skills are important for employees in the field of big data.

Royster, 2013 stated that rounded up knowledge about the industry that the BDP are employed in will uplift their contribution to the sector. In order to do so, they should possess many competencies polished with traditional and up-to-date proficiencies. Based on the responses of the questionnaire survey it was concluded that the competency level of local BDP is satisfactory when compared with foreign professionals.

H_{1c}: Job Market Factors impact the Employment of BDP

In the Sri Lankan context, JKH, 2020 and PickMe, 2016 have specified minimum two years of experience in the field, for an employee to be recruited as a big data employee. All the industry experts have commented that experience is very important when employing BDP in an organization. Similarly, big data employees mention that the experience, skills and competencies that they have acquired through past experience have immensely helped them in performing their current jobs.

Certain employees find their career path based on the prestige of the field. Similarly, BDP also consider the recognition of the profession when engaging in employment. According to Hopkins & Hawking, 2018, big data analytics is growing in recognition in the global job market with its rapid evolution and potential strategic competitive inferences. Even though big data analytics is high in recognition in the international job market, it is not so in Sri Lanka. Industry experts comment that this is mainly because the industry is still in early stages of emergence. They further explain that only the professionals in the field are aware of the term “Big Data Professionals”, and in layman terms they are referred to as “Computer Engineers”.

Carillo, et al., 2019; Carillo, 2017; Intezari & Gressel, 2017; and Murawski & Bick, 2017 stressed the importance of on-the-job training, career guidance and continuous professional development programmes to develop analytical and technological skills. Similarly, Wickramasinghe, 2017 stressed on “Retrain to retain”, to overcome the employee shortfall by training the existing workforce to possess futuristic yet vital data analytic skills.

Many experts mention that even though the existing BDP in Sri Lanka are well-knowledged and talented, there is a scarcity of professionals in order to cater to the growing demand. However, they further mention that when compared to the professionals in developed countries, local BDP have so much to develop. When considering about the age of professionals, it is very visible that most employees in the field are young and energetic, but not very mature in age.

4. CONCLUSION

The research study identified that the employability of BDP is affected by educational factors, skills and competencies and job market factors. The literature review unveiled that the big data employees are lacking in the job market at a significant level due to various weaknesses in the aforementioned three factors. Similarly, the industry experts specifically revealed the lack of engagement with the profession locally. Hence, possible actions should be taken to uplift their representation as a prestigious career by mitigating all the shortcomings. The researchers determined that the local higher educational platforms and professional qualifications should be improved and standardized as the initial steps to mitigate the skill shortage of professionals. Similarly, the local employees should be extended with systematic competency development programmes in order to continuously nurture their skills. Meanwhile, the profession should be firmly embraced and promoted by local companies with the motive of a “win-win” approach to both the company and BDP. Their remuneration should be improved in line with the amount of value addition they bring to the company. Therefore, the companies should expand their horizons to grasp this enticing field as a source

of growth and competitive advantage.

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STUDY OF THE INFLUENTIAL FACTORS IN ESTABLISHING THE ENVIRONMENTAL FRAMEWORK FOR THE GREEN BUILDING CONCEPT TO THE CONSTRUCTION PROJECTS IN SRI LANKA

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ABSTRACT

A sustainable development idea known as "green building" aims to make better use of resources such as electricity, water, materials, and land. Green buildings offer many more financial advantages than traditional structures, such as improved indoor environmental quality and water and energy savings. They also have lower operating and maintenance costs. Organizations in the Sri Lankan green construction industry should do an industrial analysis because this market is still growing and may experience challenging business circumstances. By conducting such a strategic study, they may be able to determine their own comprehensive green construction strategies. As a result, the environmental framework serves as a comprehensive and practical tool. A literature analysis and a questionnaire survey were employed in a quantitative approach to determine the barriers to adopting this concept. Common preferences and their ranking laid the groundwork for finalizing the questionnaire. PESTEL environmental framework was used to evaluate the elements that influence the acceptance of the green building idea. The findings demonstrate which environmental factors were most influential in convincing Sri Lanka's construction sector to embrace the Green Building concept. Second and third, a correlation and regression analysis were utilized to show the linkages and consequences of PESTEL perspectives discovered in Sri Lanka to adopt this notion.

KEYWORDS: Environmental Framework, Green Building Concept, PESTEL (Political, Economic, Social, Technological, Environmental, Legal), Construction Projects

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1. INTRODUCTION

Green Building (GB) is the technique of designing structures in which resources are utilized optimally throughout the building's construction process. It enables for climatic and natural environment conservation and promotes human quality of life. Not all states and countries have the same Green Building Concept due to climate, cultural, and social factors. Its productivity level significantly affects the development and expansion of the national economy. Green buildings are now considered to have significant strategic importance for the construction industry. The use of green building practices in the construction sector has the potential to increase health, safety, comfort, and environmental friendliness.

PESTEL is a strategic management tool for macro-environment scanning that is frequently applied to market research. Additionally, it is employed to assess the industry's profitability and influence (Serdar Ulubeyli, 2019). By reviewing it in regard to political, economic, social, technological, environmental, and legal elements, it is used to disclose good and negative issues that can affect the adoption of the green building approach. (Li Zhang, 2017). A detailed analysis of strategic factors can be used to understand how external and internal aspects have an impact on adopting the Green Building concept for a sustainable position in the industry. "Green building" focuses on conserving water, energy, and material resources during the development and maintenance processes. The use of the green building idea can cut carbon dioxide emissions by 35%, water usage by 40%, energy usage by 50%, and waste products by 70%. (B.A.W.P. Bombugala, n.d.). Therefore, PESTEL analysis can be used to determine the most important elements that affect and encourage the use of green buildings by analyzing the obstacles and implementations that are strongly associated to their adoption.

As a Quantity Surveyor, with the evolution of sustainable construction methods, the tasks and responsibilities of a quantity surveyor are expanding in modern QS practice. In light of this, modern quantity surveyors need to become more adept at managing life cycle costs, cost of maintenance, and

operational costs as well as leasing, purchasing green goods and services, amalgamating information, implementing green management providing services, fusing facts, and applying in green management strategies. The contributions of QSs are also apparent in the project's later stages, including the preparation of tender documents, pre-qualification of tenders, and tender evaluations. The finest contractor for a green project should be chosen based in large part on how these typical responsibilities are carried out sustainably. Due to their proficiency in cost management and familiarity with building procedures, QSs are in a crucial position to help clients achieve their sustainability targets throughout a green project. Ma & Luu, (2013). Ashworth, (2013), represents modern-day QSs doing multiplex responsibilities such as loss replacement, audits, dispute settlement, and expert testimony, as well as advice for cost-benefit analysis, whole-life costing, advice for sustainable construction, and so on because they restrict the contemporary capabilities.

With today's rapidly rising population and housing needs, the entire globe is suffering from the dire repercussions of global warming and climate change. (Khadka1, 2019). If the entire globe continues to engage in this act of global warming and climate change, then existence on Earth will become untenable. Additionally, Green building technologies (GBTs) play an essential role in reducing emissions of carbon in the construction industry. Daylighting supply in the design and construction of buildings improves the aesthetic appeal of the structure while also reducing the need of electric lighting, which saves energy and so reduces GHG emissions. The other factor is natural ventilation designs, which give the necessary thermal comfort and indoor air quality. These decrease the requirement of electrical ventilation equipment like fans and vent systems, resulting in lower GHG emissions. The thermal performance of the building governs account for providing a sustainable facade for minimizing heat transmission in and out of the structure. This reduces the cooling burden and, as a result, the corresponding GHG emissions. Energy-efficient equipment and fixtures have considered equipping the structures with sustainable switches, fixtures, air conditioning

systems, lighting systems, elevators and escalators, and so on. Providing this kind of sustainable equipment will lower related building operating energy consumption and GHG emissions. (Abdullahi Mohammed Usman, 2022). Therefore, the GB concept is very important to be adopted to the current industry practices in Sri Lanka. Unfortunately, GB practices are rarely used in the Sri Lankan context. However, as of late, there is no comprehensive study to identify the barriers for adopting the GB concept in Sri Lankan construction practices. Accordingly, this study can be more realistic and genuine when analysed within an environmental framework.

Accordingly, this study aims to identify the significant factors according to the environmental framework which have become barriers to the adoption of the Green Building concept in Sri Lanka and the objectives were listed as 1) identify the most influenced factors of the environmental framework to adopt the Green Building concept 2) identify the relationship between the environmental framework and the application of the green building concept to the Sri Lankan construction industry. As a result of the successful study, the most essential aspects based on the PESTEL analysis can be identified, and greater attention may be devoted to those factors in order to adapt the Green Building idea in the Sri Lankan environment. Several parties will gain from it, as follows.

To the government of Sri Lanka

- Identify the legal aspects and new laws that can be enacted.
- Develop the construction industry with goodwill to the society.
- Get a better idea about the cost and quality.
- Get a better idea about the increase in comfort, health, and productivity by adopting this Green Building concept to the environment
- Protect the natural environment by reducing energy consumption, reducing destruction of natural resources, reducing water consumption, and limiting waste generated.

2. LITERATURE REVIEW

2.1 Green Buildings

Sustainable development is the creation of a building that meets the needs of future generations without compromising the potential of future generations. (Illeperuma & Abenayake, 2022). There are numerous methods and tools for incorporating sustainable development features into different industries. Global recognition of Green Building (GB) as a strategy for integrating sustainability into the construction industry. (Boons & Ludeke-Freund, 2013). A "Green Building" is a building that, in its design, construction, or operation, reduces or eliminates negative consequences, and can create positive benefits, on our climate and natural environment. Green buildings are designed, developed, and maintained with the goal of providing a secure indoor environment while minimizing life cycle costs.

2.2 PESTEL Environmental Framework

Pestle is an extensive analysis technique that can assist you in building a strategic plan for your company. Systematic strategic planning must include a macro-environmental assessment. These factors will definitely have a significant impact on the success of a company and possibly even its existence (Ginter & Duncan, 1990). In order to understand an organization's strategic approach and help in making informed commitments about organizational operations, it is important to evaluate big-picture variables using a comprehensive approach. Such an evaluation can be used to originate a long-lasting merciless advantage. A macro-environmental monitoring element in the field of deliberate management is called PESTLE. (Johnson, et al., 2017). A review of strategic perspectives is useful to understand how outside drivers and barriers affect a specific area of attention for a long-term market position. Though macro-environmental conditions are expected to change over time, a comprehensive review of perspectives can help provide an early-stage view of what could be in store for us in the future.

2.2.1 Political Perspective

It may contain broad or specialized policies concerning, for example, taxation, labour, healthcare, youth development, infrastructure, bureaucratic procedures, and tariffs. (Ulubeyli & Kazanci, 2018). The application of laws, regulations, and judgments relevant to the provision of public services is supervised by democratic governance. Insufficient governmental support and promotion may be characterised as political considerations, and the lack of government incentives was highlighted as one of the top three most essential obstacles to the growth of green building, emphasising the role of government as a fundamental component. (Assylbekov, et al., 2021).

2.2.2 Economic Perspective

The most significant barrier to green construction is the cost, as it demands a larger initial investment than regular buildings. Economic fluctuations have a significant impact on construction productivity. This factor indicates microeconomic outcomes that have a major impact on an organization or industry (Assylbekov, et al., 2021). Another significant economic obstacle impeding the proliferation of green buildings is a long payback time, and as with increased prices, the additional time necessary for a green project is a critical element influencing stakeholders' decisions. In addition, the study performed in the United States identified a lack of market demand as well as risks and uncertainties associated with the deployment of new technology as critical considerations.

2.2.3 Social Perspective

A major barrier to consider is a lack of knowledge and awareness, as some studies imply that fixing it may alleviate numerous issues at once. However, because it is closely related to government incentives and educational initiatives, it may necessitate considerable effort to create awareness among stakeholders. (Assylbekov, et al., 2021). Social sustainability in the construction sector primarily refers to living standards, workplace health and safety, and future professional development chances. In the context of buildings, social sustainability involves creating a healthy and safe environment for all stakeholders, such as

construction workers, users, and operators, which should be considered during the sustainable design process.

2.2.4 Technological Perspective

The use of technical breakthroughs in renewable energy has been critical in reaching green construction goals and accreditation. One of the major issues is the absence of infrastructure linking the electricity generated on construction sites to the power grid. However, the cost, maintenance, and operation of renewable energy systems continue to be substantial barriers to the implementation of these technical advancements in green buildings.

A lack of technological improvements is also a major cause of prolonged construction timeframes. (Assylbekov, et al., 2021). Technology in the construction industry can increase productivity.

2.2.5 Environmental Perspective

Green Construction is intended to have the lowest impact on the natural environment possible by utilizing water and energy resources efficiently and bringing human health and comfort into consideration. Construction sustainability includes cost estimate decisions that enhance current and future social, economic, and environmental demands, as well as techniques for maximizing benefits in construction practices (Pan, et al., 2019). Green buildings, from an environmental standpoint, assist to promote urban biodiversity and maintain the eco-system through sustainable land use. Green buildings usually outperform conventional buildings in terms of energy efficiency, water efficiency, and carbon emission reduction. According to their findings, commercial buildings will profit the most from LEED certification in terms of CO₂ reduction, followed by residential and public buildings (Jian Zuo, 2014).

2.2.6 Legal Perspective

These highlight certain rules and regulations that may have an impact on the company environment in the industry. A lawful examination of this type may consider consumer, physical condition and welfare, publicity, occupation, and antitrust legislation. It was one of the considerations that influenced owner

decisions and top management commitment. (Ulubeyli & Kazanci, 2018). Construction contracts serve an important role in reducing legal and administrative hazards that might lead to claims. As a result of these developments, some adjustments in industry contractual practises are required. The study's conclusions seek to raise the degree of awareness among construction experts regarding such potential threats. The analysis shall also aid various contract parties in crafting specific terms to prevent likely future claims by disclosing the possible legal hazards of sustainable initiatives. (Sahra Mohammadi, 2016)

3. METHODOLOGY

In this study, a mixed research approach was used, with quantitative and qualitative methods used to identify the significant factors according to the environmental framework that have become barriers to the adoption of the Green Building concept in Sri Lanka, as well as the relationship between identified factors and the adoption of the GB concept in the Sri Lankan construction industry. To evaluate the study's aim and objectives, a wide spectrum of community members associated with the Sri Lankan construction industry were targeted, including professionals and stakeholders in the Sri Lankan construction industry.

3.1 Data Collection Methods

In this research, Stratified Random Sampling was employed as the sampling method. Quantitative data were collected through a questionnaire survey which includes different viewpoints and were ranked accordingly to the Likert Scale questions. The total number of questionnaires were distributed among 55 selected by stratified random sampling and 51 responses were received with 92.72% response rate including 05 project managers, 15 quantity surveyors, 12 engineers, 10 architects, 02 contractors, 03 consultants and other 4 people who are related to the construction industry.

3.2 Conceptual Framework

The conceptual framework which was developed for the study was illustrated in Figure 1.

The adopted green building idea in Sri Lanka has been selected as the dependent variable. It is designated as the main variable due to its significance as the primary goal of the investigation. Then independent variables were determined in consideration of the environmental framework (PESTEL) throughout the project life cycle since it was easy to identify the barriers to implement the GB concept. To investigate the relationship between the variables, both null hypotheses (H_0) and alternative hypotheses (H_1) were developed as follows. Null hypotheses (H_0): There is a relationship between the independent and dependent variables. Alternative hypotheses (H_1) imply that there is no relationship between the independent and dependent variables.

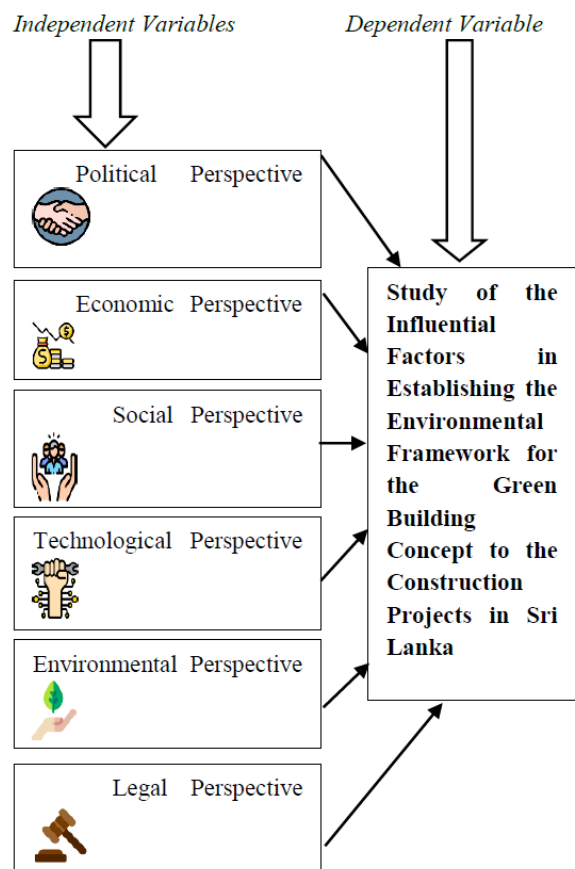


Figure 1: Conceptual Framework

3.3 Data Analysis Methods

Primary data was evaluated quantitatively. Statistical study assisted in determining the links between the PESTEL framework and the implementation of the

GB concept. This is the most effective strategy for multivariable analysis. The association is hypothesized at the start, and the statistical analysis is conducted appropriately. The analysis was carried out using SPSS analysis software, which includes a wide range of formulas and statistical methods with the help of SPSS software, regression analysis was used to determine the influence of the independent and dependent variables, and the degree of the association between the independent and dependent variables was determined by the correlation coefficient. The RII analysis approach is used to determine the most influential element in a PESTEL analysis.

3.3 Data Analysis

3.3.1 The impact of PESTEL factors on adopting the GB concept in Sri Lanka

The SPSS programme was used to do a regression analysis to determine the impact of these two factors. Regression analysis examines the relationship between the dependent and independent variables, illustrating how the dependent variable varies whenever one or more independent variables change owing to circumstances. The regression analysis formula was created as follows and the formula for the regression analysis was developed as follows.

$$Y = \{\alpha + (\beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6)\} + \text{Std.E}$$

Accordingly, Y is the dependent variable while X is the independent variable here. α is the constant and β is used to define the slope between the variables.

Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.826	.360		2.294	.027
	PM	.105	.176	.108	.594	.003
	EM	.017	.163	.008	.043	.046
	SM	.103	.151	.109	.679	.001
	TM	.369	.123	.457	3.010	.004
	ENM	.033	.162	.034	.201	.042
	LM	.393	.139	.431	2.817	.007

a. Dependent Variable: GBM

Figure 2. Coefficient table derived from SPSS software.

Figure 2 which consists of coefficients was directly derived from the SPSS software where it depicts the values to prove the relationship between the dependent and independent variables in relation to the regression analysis formula through the unstandardized B (β) value.

$$Y = \{0.826 + [0.105 \times (\text{PM})] + [0.007 \times (\text{EM})] + [0.103 \times (\text{SM})] + [0.369 \times (\text{TM})] + [0.033 \times (\text{ENM})] + [0.393 \times (\text{LM})]\} + \text{Std.E}$$

PM = Political Perspective

EM = Economic Perspective

SM = Social Perspective

TM = Technological Perspective

ENM = Environmental Perspective

LM = Legal Perspective

GBM = Green Building Adoption in Sri Lanka

This demonstrates a positive link with a 10% variance of adoption of the GB concept to the current Sri Lankan construction practice, which is influenced by the political factors of the PESTEL framework, with a beta value of 0.105 and a significance value of 0.003. The application of the GB concept to Sri Lanka's existing construction practice, which is influenced by the economic factors of the PESTEL framework, is shown to have a positive relationship with a 1.7% variance, with a beta value of 0.017 and a significance value of 0.046.

Based on the results of the regression analysis, the Legal perspective has the highest impact on the dependent variable with a 39% variance in the adoption of the GB concept in the Sri Lankan construction sector. Economic Perspective was identified as the least impact variable with the 1.7% variance of adoption of the GB concept in the Sri Lankan construction sector.

3.3.2 Identification of most influenced factor according to PESTEL framework

The PESTEL analysis of Sri Lanka's construction industry is a useful tool for ranking the barriers to GB concept implementation there. Using a Likert scale ranging from strongly disagree to strongly agree, a

relative relevance index was developed for each feature. The RII was calculated using the sum of all responses divided by the number of responses and the highest number on the Likert scale.

The RII is calculated using the sum of all responses divided by the number of responses and the highest number on the Likert scale. The RII value typically consists of a value between 0 and 1. The barrier becomes more substantial the higher the RII value. Critical impediments to implementing the GB concept in Sri Lanka were created based on the proportion of the RII values. The levels for the RII% values can be used to determine the significance of each element. The following are the levels of the RII% values. (Qui, 2014).

- Medium or non-critical (RII % < 70%)
- Critical (RII% ≥ 70%)

Table 1: Overall Relative Important Index

Factor	Average RII	Rank
Political	0.7392	3
Economic	0.6764	6
Social	0.7137	4
Technological	0.7598	2
Environmental	0.7117	5
Legal	0.8618	1

The above table shows how these factors are affected by using the GB idea in the construction industry. Legal factor is the most influenced factor and Economic factor is the least influenced factor to adopt the GB concept in Sri Lanka.

3.3.3 Relationship Between the PESTEL Environmental Framework and the application of GB Concept to the Construction Projects in Sri Lanka

Correlation analysis was done to identify the relationship between developed independent variables (IV) & the dependent variable (DV). Pearson correlation coefficient was used to check the relationship and was analysed through SPSS software. Positive correlation represents when one variable increase & the other variable also increase. A negative

correlation represents a decrease in both. The correlation coefficient will be satisfied based on significance value (P) which,

P < 0.05 – The DV has a relationship with particular IV

P > 0.05 – The DV doesn't have a relationship with a particular IV

Where: N = No of respondents (51)

		Correlations						
		PoliticalMean	EconomicMean	SocialMean	TechnoMean	EnviroMean	LegalMean	GreenbuildMean
PM	Pearson Correlation	1	.815**	.725**	.712**	.673**	.705**	.584**
	Sig. (2-tailed)		<.001	<.001	<.001	<.001	<.001	<.001
	N	51	51	51	51	51	51	51
EM	Pearson Correlation	.815**	1	.668**	.717**	.736**	.676**	.587**
	Sig. (2-tailed)	<.001		<.001	<.001	<.001	<.001	<.001
	N	51	51	51	51	51	51	51
SM	Pearson Correlation	.725**	.668**	1	.703**	.737**	.696**	.632**
	Sig. (2-tailed)	<.001	<.001		<.001	<.001	<.001	<.001
	N	51	51	51	51	51	51	51
TM	Pearson Correlation	.712**	.717**	.703**	1	.696**	.656**	.723**
	Sig. (2-tailed)	<.001	<.001	<.001		<.001	<.001	<.001
	N	51	51	51	51	51	51	51
ENM	Pearson Correlation	.673**	.736**	.737**	.696**	1	.736**	.615**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001
	N	51	51	51	51	51	51	51
LM	Pearson Correlation	.705**	.676**	.696**	.658**	.736**	1	.712**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001		<.001
	N	51	51	51	51	51	51	51
GBM	Pearson Correlation	.584**	.587**	.632**	.723**	.615**	.712**	1
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001
	N	51	51	51	51	51	51	51

** Correlation is significant at the 0.01 level (2-tailed).

Figure 3: Results of Correlation Analysis

Figure 3 illustrates that there is a correlation between the independent variables and the dependent variable. All the independent variables have a positive relationship with the dependent variable. This signifies that all the null hypotheses that were developed for the study were satisfied.

The above figure shows a 0.001 significant value between the Political factor of the environmental framework and the adoption of the GB concept. Since the significant value between those two factors less than 0.05, it is possible that there is a relationship between above mentioned two variables. Furthermore, the above table illustrates that Political factors and GB concept adoption have a 0.584 positive correlation. It is a very strong relationship. Due to that value, it is fair to say Political factors have a strong relationship with GB concept adoption. Based on that, the hypothesis which has no relationship between Political factors and GB Concept adoption can be excluded.

Accordingly, the second independent variable, Economic perspective (EM) has acquired a 0.001 significance level over the adoption of the GB

Concept as indicated in Table 4.3, and it is obviously indicated that there is a relationship between the Economic factor and the adoption of the GB Concept. Therefore, the assumption of H_{B1} of the hypothesis is accepted.

According to Figure 3, the third independent variable, Social Perspective (SM), has a significance level of 0.001 over the adoption of the GB concept, clearly indicating that there is a relationship between the two. As a result, it confirms the hypothesis, and H_{C1} of the hypothesis is accepted.

There is a relationship between the technological factor and the acceptance of the GB concept because figure 3's fourth independent variable, the Technological factor (TM), has obtained a 0.001 significance level over the adoption of the GB concept. As a result, it confirms the hypothesis, and H_{D1} of the hypothesis is accepted.

It is evident that there is a relationship between the environmental factor and the adoption of the GB concept since the Environmental factor (ENM), the fifth independent variable, has a significance level of 0.001 over the adoption of the GB concept as listed in Table 4.3. As a result, it confirms the hypothesis, and H_{E1} of the hypothesis is accepted. According to figure No. 3 interpretation, the sixth independent variable, Legal Factor (LM), has a 0.001 significant level over the adoption of the GB concept, clearly indicating that there is a relationship between these two variables. As a result, it confirms the hypothesis, and H_{F1} of the hypothesis is accepted.

4. RESULTS AND DISCUSSION

4.1 Political Perspective

According to the study, the influence of political factors is identified. In an emerging economy, a lack of subsidies may result in low market demand. This is because green construction materials may not be financially feasible at the outset, therefore money supplied by government agencies will be beneficial in bridging this gap. Subsidies in this scenario might

compel a government to overcome early economic obstacles facing the industry. Tax policy is a strategy for dealing with human, organisational, and institutional shortcomings in the green building movement. Construction materials and technology may face higher taxes in a burgeoning green building industry, while existing levies on green products may be reduced. Giving these fiscal incentives to the business appears to impose a cost on the public sector by increasing the savings of green building constructors and owners. Political stability is essential for assembling macroenvironmental elements and sub-factors in an integrated way. Otherwise, it may be difficult to take advantage of the benefits that other elements might provide.

4.2 Economic Perspective

In this category, real estate values are extremely important. Based on a large sample size in the statistical analysis, prospective consumers should evaluate life cycle costs, which may result in significant financial savings from energy expenses in the long term, rather than only the initial investment cost. Exchange rates are one of the most essential costs in any economy since they influence all other prices, including those of environmentally friendly green items. Furthermore, government guarantees on fixed exchange rates may be one of the most effective ways to minimise possible exchange rate risks. In terms of interest rates, building activities are more susceptible to changes in long-term interest rates. This is due to the fact that contractors often have bank credit for continual financial flows of material, equipment, and labour supply. Inflation in a local economy could threaten the successful completion of traditional and green building projects. Income per capita is empirical data demonstrating a positive relationship between income and willingness to pay for environmental amenities. The study shows that willingness is positively associated to the adoption of energy efficient and sustainable construction practises, and that its spread is faster in higher-income urban regions.

4.3 Social Perspective

The impression of comfort or living quality was discovered to be the most important. Interior environment quality, including temperature and air in winter and summer, lighting, noise, and general interior comfort, are examples of comfort considerations. Addressing a potential occupant's purchasing behaviour on green buildings requires raising awareness via education. Improving public knowledge of green buildings can result in more educated consumers who will support green building development. Both a lack of customer interest in green construction and a lack of societal market demand are important barriers to green building project management.

4.4 Technological Perspective

Green building construction does not have to involve an additional contract obligation or an associated risk that a contractor must manage. In this sense, a green construction contractor should aim to communicate more about green concerns with the customer, end-users, consultants, and subcontractors. Green construction materials have a fast-developing market today. These materials should be harvested, processed, and produced on a regional scale, utilising recycled and bio-based raw resources. There is no fixed material market required for the development of green buildings. Creating such a market is likely to be a critical first step for high-scoring green buildings. Given the level of modern technology or automation, particularly in self-sufficient buildings, high-tech systems are required in general. There are several angles to examine in terms of the amount of innovation. Green certifications, for example, need credit areas such as design innovation. The use of renewable energy technical breakthroughs is also critical for reaching green construction aims and accreditation.

4.5 Environmental Perspective

Some issues, for example, architectural/mechanical designs, renewable energy purchases, and greenhouse

gas emissions may have priority in this regard. A comprehensive energy-efficient building design strategy can lower the size of mechanical systems, offsetting the higher cost of energy efficiency measures. Simple and effective practices may protect the environment and provide solid economic rewards. Furthermore, in today's green-focused economic climate, construction firms must embrace excellent environmental practices in order to preserve a competitive edge in the market. Green building materials are manufactured from recycled resources and are recyclable, and a recycled construction materials industry is critical. Despite the slow development of this sector throughout the world, it appears unavoidable to establish a local market. Although geographical location appears to be mostly tied to anticipated customer demand and land cost, it offers the particular advantage of modelling building energy usage as well.

4.6 Legal Perspective

As the most influenced factor according to the RII analysis, a green construction process is required to correspond to the environmental standards of the nation of origin; therefore, a government must first establish applicable legislation and compel green building enterprises to follow them. As a result, the long-term effects of environmental rules on the green construction industry and corporate structure will be the creation of a full-fledged recycling sector, significant expansion in the secondary goods market, and circular supply chains. Many green building certificates have been produced in various nations as a result of the adoption of a certification system. They are created to give impartial assessment criteria and to assist the processes of sustainable design. In terms of import laws, it should be emphasised that financial and technological hurdles to the import of green materials and equipment may stymie the local manufacturing industry's development.

5. CONCLUSION AND RECOMMENDATIONS

The study's major purpose was to ascertain the impact of key aspects on the environmental framework

implementation of the GB concept in the Sri Lankan construction industry. Green architecture was presented as a solution to a variety of social, economic, and environmental challenges. It is a developing concept that is resonating all over the world. The study provides the following recommendations to assure the success of the GB method based on the results of questionnaire survey responses. According to this study the results are the same when analyzed with different analysis methods. It is called Data Triangulation. Data triangulation is the utilization of many data sources in a study, encompassing time, place, and people. Findings may be confirmed, and any shortcomings in the data can be compensated for by the strengths of other data, boosting the conclusions' validity and dependability. According to that, the validity level of these data is high.

Green buildings will eventually take center stage in the culture of the construction industry to attract clients, promote peace between man and nature, and develop shared growth circumstances. People have more time to focus on subjects other than economics because their living conditions are deteriorating as a result of economic globalization and technological improvement. This research was only carried out to identify the construction barriers of a building and the operation barriers of a building is not included for this study. The study's major purpose is to ascertain the impact of key aspects on the environmental framework implementation of the GB concept in the Sri Lankan construction industry. Green architecture was presented as a solution to a variety of social, economic, and environmental challenges. It is a developing concept that is resonating all over the world. The study provided the following recommendations to assure the success of the GB method based on the results of interviews with industry professionals and questionnaire survey responses. The government could hold an annual awards ceremony and provide special gifts to encourage and promote GB construction. According to industry analysts, this refers to the incentives provided by enforcing the law. Legislators give the incentives envisioned by governmental legislation or a legal obligation inside a governmental setting. The GBCSL

aims to introduce a new perspective to the sustainable future of the building sector, and it will be the following generations that adopt these many ideas via practice. The whole-school method involves linking the curriculum to the outside environment right where students are learning. Green structures serve as a tangible symbol of this connection and connect the curriculum with the outside world. All the projects must be monitored by a green expert who can monitor the progress of the site according to guidelines. Then the disputes can be reduced easily regarding the green parameters. Project can be easily completed according to the green practices with the advice from the green expert. modern Green techniques such as self-employment for village people are a viable way to increase the availability of green construction materials. Incentives, interest-free loans, tax exemptions, and other benefits can also be used to encourage the creation of green products. Cities, parks, train stations, bus stops, universities, hospitals, public libraries, and government offices should be the first.

Abbreviations

- GB- Green Building
- GBT- Green Building Technology
- GHG- Green House Gases
- QS- Quantity Surveying
- RII- Relative Important Index
- SPSS- Statistical Package for the Social Sciences

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THE IMPACT OF LEAN CONSTRUCTION TOOLS ON THE REDUCTION OF CONTRACTOR-RELATED CAUSES OF DELAY IN SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

Though lean construction is abundantly used in other countries, it is an underrated concept when it comes to Sri Lanka. Past research studies collectively demonstrate that construction industry in Sri Lanka is lagging in the effective implementation of lean in construction processes. Demonstrating the effectiveness of the lean construction tools to mitigate causes of delay will be a future research concern. Since, delays are still taking place within Sri Lanka, it is crucial to look at how lean construction tools can affect to reduce construction delays. This paper aims to identify the impact of Lean Construction Tools (5S, Last Planner System, Visual Management, First Run Studies) on reduction of Contractor related causes of delay. This was met by utilizing a mixed research methodology, which includes both the gathering of quantitative data through a questionnaire survey and the gathering of qualitative data by conducting semi-structured interviews with construction industry specialists. SPSS software was used to analyze data collected from the questionnaire survey, and content analysis was used to examine data obtained from the semi-structured interviews. The results revealed that implementation of Lean Construction Tools can lead to reduction of Contractor related causes of delay. Further, it was disclosed that 5S is the Lean Tool that has the highest impact on reduction of Contractor related delays. Findings have also revealed that lack of awareness about Lean Construction is the most critical challenge for successful implementation of Lean Construction Tools within Sri Lanka. The results depict that in order to overcome this barrier awareness on Lean Construction must be enhanced among construction industry professionals.

KEYWORDS: *Lean Construction Tools, Contractor Related Causes Of Delay, Construction Industry, Sri Lanka*

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1. INTRODUCTION

In construction, delay is the period of time that elapses after the completion date specified in the contract and as mutually agreed upon by the contract's parties. Delay is one of the most reoccurring issues in the construction sector around the world. Contractor is the party that is mostly responsible for construction delays (Farooqui, 2007). In Sri Lanka, the majority of construction projects are prone to delays and timely completion is typically rare. Although there are delay mitigation strategies, they are not effectively used in Sri Lankan construction industry (Jayalath, 2010).

The foundation for this lean approach is decreasing waste throughout the process and attempting to make tasks as simple to comprehend, initiate, and manage as feasible is the basic concept behind the term "Lean". (Ansah, 2016). Lean construction tools are designed to improve project performance by eliminating waste and increasing project value. It aids in increasing productivity, minimizing time and ultimately increasing client satisfaction (Akinradewo, 2018).

Countries such as UK, USA and Singapore have achieved sustainable benefits by implementing lean construction, and it is the best time for the Sri Lankan construction industry to consider about implementing lean construction in order to improve overall performance (Thilakarathna & Senaratne, 2012). Since lean construction tools have proved their effectiveness over the past years, and project delay is a common problem every Sri Lankan construction project faces, instead of dealing with causes of delay, an effort should be taken to facilitate the timely delivery of future construction projects in Sri Lanka (Thilakarathna & Senaratne, 2012). Gomez-Cabrera (2020) has established that lean construction tools can be assigned to mitigate factors contributing to delay and has further emphasized that more than one lean tool can be used to reduce the effect of a single factor.

Adapting a large number of lean construction tools at once is not practicable and the purpose of all lean tools is not reducing time overrun. Therefore, 4 lean

construction tools which can be adapted in order to mitigate delays have been chosen for the study. Since Contractor is the party that is mostly responsible for construction delays, this paper addresses mitigating causes of delay over which the Contractor has control by adapting lean construction tools.

A: Contractor Related Causes of Delay

A research conducted on construction project delays in Florida State in USA by Sayad (2002) shows that various stakeholders are responsible for the overall project delay in the following ways; Contractor = 44%, Owner = 24%, Government = 14%, Shared (between Owner & Contractor) = 12% and Consultant = 6%.

A study carried out by Farooqui (2007) on delays within Pakistan construction industry depicts that several stakeholders are accountable for the entire project delay in the following manner; Contractor = 48.75%, Consultant = 17.5%, Owner = 16.25%, Government = 8.75%, Shared = 8.75%.

According to above researches, it is obvious that Contractor is the party that is mostly responsible for construction delays. Therefore, taking an endeavour on mitigation of Contractor related delays can significantly effect on reducing construction delays.

There are many research studies conducted in different countries in order to identify Contractor related causes of delay. Poor site management, poor communication and coordination and ineffective project planning are the common causes for Contractor related delay in Indian construction industry (Das & Emuze, 2017). According to a research done in Sri Lanka by Kesavan (2015) it was highlighted that ineffective project planning and scheduling is the most prominent cause for Contractor related delays in construction industry in Sri Lanka.

A research done in Malaysia, Yap (2021) has established that rework due to errors in construction and low productivity of labour are among the most common causes of Contractor related causes of delay

in Malaysian construction industry. Rework due to errors in construction is the most significant cause of delays attributable to Contractors in Sri Lankan construction industry (Jayasinghe, 2019).

According to Ibranke (2013) resource shortage and inadequate cash flow management are the common causes for Contractor related causes of delay in Nigerian construction industry. Sivrajah (2021) highlighted that due to the current economic crisis in Sri Lanka, resource shortage (material, labour, machinery and equipment) is the most common reason for Contractor's inability to complete the project within agreed period of time.

B: Contractor Related Delay Mitigation Strategies

Tharsan (2020) has mentioned that the majority of earlier studies revealed measures to mitigate delays in the construction industry, but they are common strategies, and further he has identified 15 applicable mitigation strategies in the Sri Lankan construction context to mitigate contractor's causes of delays. Dolage (2015) has identified 10 mitigation measures and Kesavan (2015) has established 7 delay mitigation strategies to mitigate Contractor related delays that occur in Sri Lankan construction industry.

According to above mentioned literature, identified delay mitigation strategies to mitigate Contractor related delay are; effective project planning and scheduling, maintaining positive financial stability, well qualified and experienced professionals and staff, risk analysis and management, selection of suitable Sub-Contractor, effective site management and supervision, collaborative working environment in construction, proper material procurement, continuous monitoring of construction site and effective human resource management.

C: Lean Construction Tools that Can be Adapted to Mitigate Contractor Related Causes of Delay

Lean construction tools attempt to improve delivery systems and procedures by eliminating waste,

promoting productivity, enhancing health and safety and satisfying customer expectations (Anash, 2016).

1) 5S: 5S is a fundamental lean tool to maintain work flow efficiently. The 5S process consists of five steps that can assist a workplace get rid of waste and improve process efficiency. The 5 S's of lean are Sort (Seiri), Set in Order (Seiton), Shine (Seiso), Standardize (Seiketsu), and Sustain (Shitsuke) (Salem, 2014).

The principal component of 5S is 'Sort' (Organizing). Simply, it is the efficient use of the available space. Sort can be advantageous in reducing the searching time for a material/document. The main aim of Set in order of 5S is to provide an efficient workspace by defining a designated storage area. It helps in preventing material and document mismanagement. Shine in 5S signifies cleaning. It contains a thorough examination of the workplace, increased cleanliness and the creation of an ideal working environment for employees. Standardize means creating a consistent approach for performing tasks and procedures by establishing the procedure for maintaining the first three pillars. Sustain implies maintaining & implementing all 4 components mentioned above and making it a practice to follow and maintain appropriate processes (Ghule, 2020).

2) Last Planner System: The Last Planner System (LPS) is the most well-known tool in lean construction (Akinradewo, 2018). LPS is a planning method, and it helps to reduce workflow unpredictability. Porwal (2014) has identified that pros of LPS are improved construction planning, better site management, better communication and greater collaboration amongst the stakeholders.

The LPS has five steps in its planning process: master scheduling, phase scheduling (pull planning), look ahead planning, weekly work planning and percentage plan complete (PPC). Master schedule is the complete project timetable with milestones. The phase schedule which is developed by the teams working on every phase, is more informative when compared to the master schedule. It must be ready at least six weeks before the number one activity (Akinradewo, 2018). Look ahead plan organizes the workflow in the best

possible order. Weekly work plan meetings address quality concerns, safety concerns, the weekly schedule, material demand and construction procedures. PPC assesses the number of the team's weekly assignments that are finished on time (Porwal, 2010).

3) Visual Management: The primary goals of visual management are to promote the widespread flow of information within the workplace and to reduce obstacles to that circulation of information. By providing access to information to all project stakeholders, visual management increases organizational transparency. It presents information via visual signs rather than words, making it easier for all project stakeholders to understand (Singh, 2021).

Visual management boards with all the pertinent information updated are kept in the centre of the workplace. Numerous visual management methods and tools are available such as organizational chart, gantt chart, value stream maps, kanban boards and project performance chart (Tezel, 2017). One of the most crucial concepts in visual management is the "Big Room," where all project related information is exhibited via display boards, diagrams, and colour coding (Singh, 2021). Every day construction professionals gather for a daily meeting which is around 15 minute meeting in the big room, where they use various visual tools on display to address issues present at the site.

4) First Run Studies: A first run study is a trial execution of a procedure with the aim of determining the most appropriate methods, strategies and sequencing for the process to be carried out. They are applied to redesign crucial assignments (Salem, 2005). It is a part of the effort to continuously improve; these attempts consist of productivity studies and work method reviews by restructuring and simplifying the various tasks involved. These studies frequently use photos, video clips, and graphics (3D illustration) to demonstrate a process or provide work instructions (Alarcon, 1997). The assignment chosen for the first run study should be thoroughly explored, offering recommendations and ideas to examine

alternate methodologies for carrying out the activity. A PDCA cycle (Plan, Do, Check, Act) is recommended to develop the study (Alarcon, 1997).

The objective is to carefully plan and investigate first runs of crucial tasks, using previous studies as a guide and developing standard work procedure designs for the project. The cost, errors, and accidents are reduced because of this experimental strategy, which develops a tested method that all crews can learn. It will be simple to test out new work process designs, new technology and tools, as well as various crew combinations, etc. once these studies become a routine part of the organization (Alarcon, 1997). A key component of first run studies is the integration of all performance criteria into work process design, with safety being prioritized over quality, time, and cost. That can be planned and analyzed for actual results to distinguish between plan quality and plan execution defects, allowing each to be addressed and improved.

2. METHODOLOGY

The research study is targeted to identify the impact of lean construction tools on reduction of Contractor related causes of delay in construction industry in Sri Lanka. The entire research was appraised through questionnaire surveys and interviews held among construction industry professionals in Sri Lanka. This was a combination of both qualitative (interviews) and quantitative (questionnaire survey) analysis.

A; Data Collection Methods

A detailed questionnaire was circulated across the professional groups within the Sri Lankan construction sector. A web based questionnaire (Google form) was designed and distributed via e-mail and social media among construction industry professionals actively employed in the industry. The respondents were asked to rank the different viewpoints according to a "Likert Scale". The questionnaire was distributed among 40 number of professionals (selected through stratified random sampling method) from various disciplines including Project Managers, Construction Managers, Engineers, Quantity Surveyors and Architects because based on

the perspective of different people the answers to the questions may vary due to their thinking capacity, knowledge and industry experience. Out of them, 35 responses were received, reflecting an 87.5% response rate.

To attain the aim of this study, semi structured interviews were conducted using open ended questions. The related areas can be broadly discussed by conducting semi structured interviews (Sadan, 2014). The interviewees were chosen by employing the purposive sampling method.

B. Conceptual Framework

The overall research methodology is based on this conceptual framework.

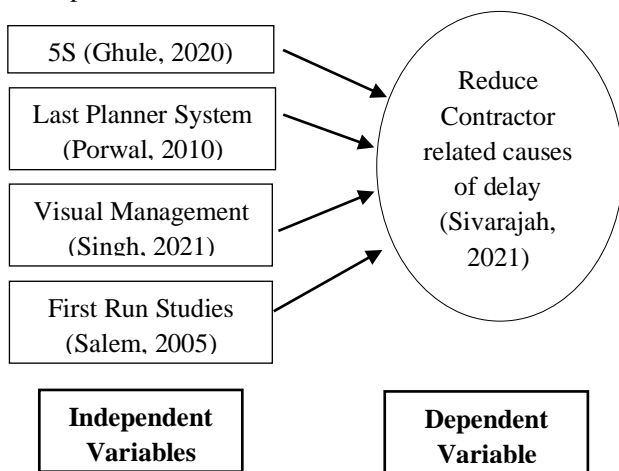


Figure 1: Conceptual Framework

Independent Variables (IV) are identified to determine the effect of each one of them against the Dependent Variable (DV) of the study. By considering the conceptual framework, assumptions were developed. For the purpose of examining the agreement among the respondents on reduction of Contractor related causes of delay by adapting lean construction tools, the hypotheses were developed as follows.

HA₁: There is a relationship between 5S and Reduce Contractor related causes of delay.

HB₁: There is a relationship between Last Planner System and Reduce Contractor related causes of delay.

HC₁: There is a relationship between Visual Management and Reduce Contractor related causes of delay.

HD₁: There is a relationship between First Run Studies and Reduce Contractor related causes of delay.

C. Data Analysis Methods

To check the hypotheses of the study, statistical data analysis was used. The establishment of the relationship between the independent and dependent variables was done through Correlation Analysis. The regression analysis was utilized to assess the influence or impact of the independent variables on dependent variable. This analysis was carried out using the SPSS software, which provides a diverse set of formulas and statistical techniques. Data obtained through semi structured interviews was analysed by using content analysis. Representation of data was done in the form of tables.

3. RESULTS AND DISCUSSION

It was investigated whether the professionals had experienced Contractor related delay. More than 90% of respondents had Contractor related delay on construction projects, highlighting it as a severe issue in the construction sector and the need for efforts to mitigate Contractor related delay in projects.

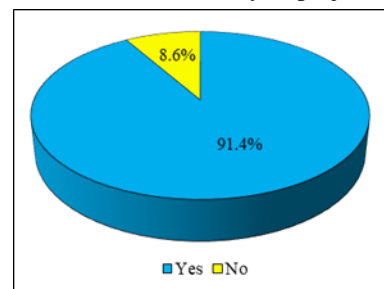


Figure 2: Experience in Contractor Related Delay

A: Correlation Analysis

The data obtained from questionnaire which was in the form of Likert scale were analyzed using SPSS

software to verify the relationship between the IV and DV.

The ‘‘Pearson Correlation Coefficient’’ was applied by using the SPSS software in this study because it offers an indicator of linear relationships between two variables that range from -1 to +1. When two variables are positively correlated, it implies that when one variable's value increases, value of the other variable also increases. When two variables are negatively correlated, it denotes that as one variable's value rises, the value of the other variable drops. Relying on the significance value (P), the correlation coefficient will be satisfied. If $P < 0.05$, the DV has a relationship with the particular IV and If $P \geq 0.05$, the DV does not have a relationship with particular IV.

Table 1: Correlation Analysis (SPSS Generated)

		Correlations				
		AVGA	AVGB	AVGC	AVGD	AVGE
AVGA	Pearson Correlation	1	.066	-.200	.047	.479**
	Sig. (2-tailed)		.707	.250	.790	.004
	N	35	35	35	35	35
AVGB	Pearson Correlation	.066	1	.037	-.169	.397*
	Sig. (2-tailed)	.707		.832	.333	.018
	N	35	35	35	35	35
AVGC	Pearson Correlation	-.200	.037	1	.274	.499**
	Sig. (2-tailed)	.250	.832		.111	.002
	N	35	35	35	35	35
AVGD	Pearson Correlation	.047	-.169	.274	1	.386*
	Sig. (2-tailed)	.790	.333	.111		.022
	N	35	35	35	35	35
AVGE	Pearson Correlation	.479**	.397*	.499**	.386*	1
	Sig. (2-tailed)	.004	.018	.002	.022	
	N	35	35	35	35	35

** . Correlation is significant at the 0.01 level (2-tailed).
* . Correlation is significant at the 0.05 level (2-tailed).

Where,

N = No of Respondents

AVGA = Average of 5S

AVGB = Average of Last Planner System

AVGC = Average of Visual Management

AVGD = Average of First Run Studies

AVGE = Average of Reduce Contractor related causes of delay

Table 1 depicts the results of the correlation analysis. Since the Pearson correlation of all variables range from -1 to +1 and $P < 0.05$, it was proved that all the identified IV (5S, Last Planner System, Visual

Management and First Run Studies) have a positive relationship with the DV (Reduce Contractor related causes of delay).

B. Regression Analysis

This was conducted in order to ascertain which independent variable has the maximum impact on the dependent variable. The identical set of data retrieved through questionnaire utilized for the correlation analysis were analyzed in regression analysis by using SPSS software.

Table 2: Model Summary of Regression Analysis

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.884 ^a	.782	.753	.161

a. Predictors: (Constant), AVGD, AVGA, AVGB, AVGC

The predicted R^2 of the model is displayed as 0.782. This value reflects the extent of relationship between lean construction tools and the reduction of Contractor-related causes of delay, and it is approximately 78.2%.

Table 3: Regression Analysis (SPSS Generated)

Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.659	.515		-1.280	.210
	AVGA	.345	.056	.543	6.176	<.001
	AVGB	.340	.076	.390	4.470	<.001
	AVGC	.325	.058	.515	5.629	<.001
	AVGD	.215	.069	.285	3.133	.004

a. Dependent Variable: AVGE

The unstandardized β value or coefficients of the regression portray the percentage of reduction in Contractor related causes of delay (DV) reflected by lean construction tools (IV).

The relationship of the above regression model can be explained as mentioned below

$$Y = \alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \text{Std.E}$$

Equation 1: Linear Regression

$$Y = -0.659 + (0.345*AVGA) + (0.340*AVGB) + (0.325*AVGC) + (0.215*AVGD) + \text{Std.E}$$

Equation 2: Linear regression (Based on SPSS generated data)

According to Table 3, it is depicted that the reduction of Contractor related causes of delay increases by 34.5% with the increase of properly implemented 5S, the reduction of Contractor related causes of delay increases by 34% with the increase of properly implemented Last Planner System, the reduction of Contractor related causes of delay increases by 32.5% with the increase of properly implemented Visual Management, and the reduction of Contractor related causes of delay increases by 21.5% with the increase of properly implemented First Run Studies.

4. CONCLUSION

The study was conducted to investigate the impact of lean construction tools on reduction of Contractor related causes of delay. As per the conducted Correlation Analysis, all the mentioned hypotheses were satisfied indicating that there is a positive relationship between lean construction tools and reduction of Contractor related causes of delay. According to the Regression Analysis, 5S is the lean tool that has the highest impact on reduction of Contractor related delays.

Through the interviews it was revealed that there are barriers to implement lean construction tools within the Sri Lankan context. Identified critical implementation barriers were lack of awareness on lean construction, lack of technical knowledge and initiative in industry professionals, reluctance to adapt to new methodology, lack of agreed implementation framework and lack of government support.

5. RECOMMENDATIONS

Conducting awareness programmes on lean construction, testing the lean construction tools for a short period project with professional staff, increasing team work and encouraging top level management of the company to implement lean construction tools within their company are short term recommendations

to overcome implementation barriers of lean construction tools.

Providing proper education on lean construction, providing proper training on lean construction, designing a proper implementation framework, carrying out a case study to identify benefits of lean construction, establishing a government institute for lean construction in Sri Lanka and increasing implementation of new technology in construction industry are long term recommendations for successful implementation of lean construction tools within Sri Lanka.

Research Limitations

This research was limited to the delays in Sri Lankan construction industry and Contractor related causes of delay, and it was limited to the lean construction tools considered with delay. It was also limited to the lack of expertise available in the Sri Lankan context regarding lean construction, to the lack of knowledge of interviewees on lean construction, and to the lack of time availability. The proposed recommendations stated in this research are as per the opinion and experience of professionals in the industry.

Future Research Directions

In the future, one can develop a framework to implement lean construction tools within the Sri Lankan context. Further, one can engage in finding the impact of lean construction tools on reducing cost overrun of construction projects in Sri Lanka. One can undertake a case study on implementing lean construction tools as a solution to mitigate Contractor related causes of delay in the construction industry in Sri Lanka.

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EXPLORING THE USAGE AND DEVELOPMENTS OF THE COLLECTION OF THE CEYLON ROOM AT THE LIBRARY IN UNIVERSITY OF SRI JAYEWARDENEPURA


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ABSTRACT

Presently, being one of the largest universities in Sri Lanka in terms of student number, the University of Sri Jayewardenepura (USJ) is a leading higher education institution with diverse courses, research and inventions. The main library of USJ exceeds fifteen thousand members in its user community, including 862 permanent academic staff. The Ceylon Room (CR) Collection is considered one of the most valuable collections in the library of USJ. CR Collection consists of various printed materials significant to Sri Lankan literature. The first objective is to assist the user community in their academic endeavors and to observe the Ceylon Room usage and development needs. The other objective of this study was to find out whether the users are satisfied with the existing CR Collection. Data was gathered from the library usage records, structured interviews and through questionnaires distributed among students and academics who visited the Ceylon Room from May to August 2021. The purposive sampling method was applied, and the sample for this study was taken from three faculties out of ten faculties of the university which directly have access to the main library, i.e., Humanities and Social Sciences, Applied Sciences and Management Studies and Commerce. The available library statistics were used as primary data obtained from the records in the CR collection from 2015 to 2019. Results revealed that, most students and academic staff were satisfied with the CR Collection, and the satisfaction rates were 80% and 53%, respectively. The highest usage of the CR Collection by students is from the Faculty of Humanities and Social Sciences (FHSS) (78%), and the least usage of the CR Collection is from the students of the Faculty of Applied Sciences (FAS) (1%). Most of the academic staff of FHSS (65%) have indicated that they used the CR Collection during 2015-2019. During that period, the least number of academic staff members that have used the Ceylon Room belonged to the FAS, which is 6%. Results showed that academic staff and students of FHSS using the existing CR Collection are 65%. Therefore, the library should give more attention to the faculties of the Applied Sciences and Management Studies and Commerce to make their students and academic staff aware of the availability and new additions of the CR Collection. Furthermore, the collection should be continuously re-evaluated to meet user requirements to support their academic activities.

KEYWORDS: Academic Libraries, Ceylon Room Collection, Sri Lanka, Univ. of Sri Jayewardenepura, User Survey

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1. INTRODUCTION

The University of Sri Jayewardenepura library, which was established in 1979, has a long history. The library was established in 1959 as the Sri Lanka Vidyodaya University Library. It started with a small collection of books in the Vidyodaya Pirivena and a private collection of the most Venerable Welivitiye Sri Soratha Thero.

Presently, being one of the largest universities in Sri Lanka in terms of the student number, the University of Sri Jayewardenepura (USJ) has become the third-best university in Sri Lanka according to the THE World University Rankings 2024 (2023), with its diversity of courses, research and inventions. USJ library exceeds fifteen thousand users in its community, including 862 permanent academic staff. USJ library caters to a large user community associated with ten faculties. It supports the three main pillars of the university; teaching, learning and research with its vast resource collection. It is a fully-fledged library with nearly three hundred thousand books, reputed journals, and access to many electronic books, journals and databases.

At the beginning of the library, there were two collections, namely, the Lending and Reference. The CR Collection, which currently has a valuable collection of books, is considered one of the best sections of the library. It was started during 1966/1967 to preserve Sri Lankan publications authored by Sri Lankans and other cooperative bodies. It also houses materials written about Sri Lanka. The Ceylon Room collection also considered as a rare collection of the USJ library comprises of various printed materials related to history of Sri Lanka and with local significance. Apart from that, the collection consists of publications of scholars of USJ, important government publications such as acts, bills, administrative reports, bank reports, reports of corporations, boards, and authorities and a collection of palm-leaf manuscripts. Postgraduate theses submitted to the USJ and theses submitted by academic staff members of USJ to other universities are also housed in the CR collection. In addition, the

publications written about the university's history from 1959 onwards are stored in the CR collection. Furthermore, the collection of newspaper articles about the USJ has added historical value to the CR collection. The existing collection in the Ceylon Room is open only for reference purposes.

The book with accession number 2, the second book acquired by the library has also been kept in the Ceylon Room securely because it is the most suitable place to preserve the original copies from dilapidation. Thus, the CR collection holds a special place in the library and was also established to preserve rare and unique reference materials to provide an efficient service to the user community of the university.

It is vital to examine the usage of this valuable collection of information sources and implement strategies to increase the usage. Therefore, this study contributes to the improvement of the CR Collection of the USJ Library to provide quality service and describes the information needs of the users of the CR Collection. Furthermore, this research explores the views of the users about the CR Collection. Thus, the usage and development requirement of the Ceylon Room is essential to assist in providing the best possible service to the user community for their academic activities.

Objectives

This study aims to determine usage and development of the information resources of the CR Collection of the Library University of Sri Jayewardenepura. To achieve this aim, the following specific objectives were stated.

- To identify the user satisfaction of the CR Collection.
- To make suggestions to enhance the CR Collection and its usage.

2. LITERATURE REVIEW

Most researchers have identified the changing needs of users with the advancement of technology as users' information needs (Kebede, 2002). Like many other

sectors, academic libraries also have to focus on changing information needs of users, especially in an electronic information environment. According to Nawarathna and Singh (2013) university libraries in Sri Lanka face many challenges in the global digital environment. This shows that digitalization has a significant impact on fulfilling the information needs of the users. To meet the information needs of users in the modern era, librarians must be able to recognize and categorize different users and their diverse information needs. Nawarathna and Singh (2013) suggest that the library management should answer the right questions, 'who are the customers? what do they want?', and what can the organization provide?'. However, when it comes to user satisfaction, attention must be given to various factors, other than satisfying information needs.

According to the library user survey conducted at the University of Jaffna, Hoole (2017), points out that the development of library systems has not been uniform all around the world. Even though developed countries have been able to expand the services incorporating technology abruptly, in developing countries, adaptation to new technologies has happened at a much slower pace. Further, when it comes to the availability of resources and user satisfaction, Hoole (2017) states that the students of the university feel that more e-resources in Tamil medium should be available. By e-resources they mean access to online full-text journals, databases, e-books, online indexes, dictionaries, encyclopedias and newspapers. This finding shows that the medium of study also matters when it comes to the information needs of library users. Furthermore, students feel that the availability of recent publications needs to be improved. This stresses that the accessibility of timely information is of much value over the quantity of information available in a library. The library management can conduct user surveys and collection reviews to make more relevant information resources available.

According to Leupp (1924), "the library is the heart of the university". Also, in a study conducted at the main library, the University of Peradeniya, Gunasekara (2010) gives the idea that the academic

library is the "heart" of the learning community. This idea stresses the vitality of library services in enriching users with new knowledge. The purpose of the study by Gunasekara (2010) is to help improving library services by identifying the level of existing resources and the overall satisfaction of library users. To gather data for fulfilling the goals she mentioned, a survey method was used with a questionnaire that included both open-ended and close-ended questions linked to a five-point Likert scale. According to Gunasekera (2010), most users are satisfied with the available resources. Most of the satisfied users have visited the library on daily basis. However, the users have commented that there should be more copies of textbooks on various subject disciplines. They stress the need for more comprehensive user awareness through library orientation for the productive use of the library. Also Gunasekera (2010) stresses that underutilization of available resources is considered a pressing issue and it should be addressed vigilantly.

According to Vijeyaluxmy (2015), a vital role of an academic library is to provide information and knowledge to students from multi-dimensions. Further, the study of Vijeyaluxmy (2015) proposes that the library is an entity to provide teaching, learning and research support activities in a university. In the study of student satisfaction with the library services of the Trincomalee campus, Vijeyaluxmy (2015) states that the library services of the campus have a moderate level of agreement for the overall services. Most of the users visit the premises frequently. They come to satisfy the needs of studying various subject disciplines and also for recreational reading. Vijeyaluxmy (2015) has discussed the areas which need continuous improvement in library services. Based on user surveys, she emphasizes that efforts must be taken to add the latest editions of available textbooks and ample copies for the users to use without any hindrance. Further, this study stresses the importance of having a sufficient number of computer terminals to access OPAC (Online Public Access Catalogue) to assist the users in locating resources enabling proper utilization of resources.

The case study on "Library services and user

satisfaction in developing countries: Punjab Institute of Cardiology” by Mairaj and Naseer (2013) states that library management should pay attention to strengthening the services which the users are already satisfied with. This research dives deeper into all the supporting factors essential to make the library environment user-friendly, namely library hours, space, furniture, lighting, heating, noise level, adequacy and organization of library collection, circulation system, reference service and attitude of library staff. Overall ratings for all the concerned factors are satisfactory. However, some respondents have stressed the need to develop ICT facilities. Further, Mairaj and Naseer (2013) discuss the need to train the supporting staff on various available resources to guide library users.

A study on factors affecting user satisfaction by Kaushamalika and Weerakoon (2020) suggests that there is equal importance to all complementary services, just as the quality of the content available in the library. These factors include seating capacity, lighting, cleanliness and also photocopy services. This study emphasizes the positive attitudes of library users about the library setting, which affects the usage of library resources. With the improvements in technologies, better internet access is also considered an important service available within the library premises.

Tiemo and Ateboh (2016) consider that extensive internet accessibility and renewals of regular library services are essential elements of library user satisfaction. Similarly, Hindagolla (2021) points out the significance of online resources is of the greatest importance in today's digitalized environment. However, factors including lack of adequate computer access, poor WiFi connectivity, and users' inexperience with the library website have resulted in their displeasure. These results suggest that if consideration is given to online resources and dependable, easily accessible library technology infrastructure, the satisfaction of library users can be raised.

Idiegbeyan-Ose and Esse (2013) assert that Covenant University's library must continue to provide the best

resources and services to the university's students since these factors will increase customer satisfaction. In addition, photocopying, scanning, and binding services must be improved. The library needs to capitalize on its advantages while also addressing its weaknesses. In conclusion, a library or information centre's ability to satisfy users is its hallmark as it increases user happiness. Therefore, managers of libraries and information centres should pay more attention to the quality and quantity of library content and services.

Considering the results of similar studies done on academic libraries, it is apparent that the traditional notion of a library system is no longer valid in this new era which has intermingled with digitalized content and digital infrastructure (Hindagolla, 2021). Moreover, changes in library systems in the past few decades and upcoming changes in every field with accelerated technological progress suggest that library management must maintain library services to meet the needs of its users. Therefore, continuous improvement is a much-needed aspect of maintaining and strengthening existing library resources to cater to every conceivable need of library users, predominantly the need for sources of information.

3. METHODOLOGY

This study was conducted as a survey. Respondents were the users of the Ceylon Room Collection of the University of Sri Jayewardenepura. The purposive sampling method was applied. The data used in this study were collected from library usage records. The sample was selected from the users to the CR who belong to the three faculties of the university for which the main library mainly caters, i.e. the Faculty of Humanities and Social Sciences (FHSS), the Faculty of Applied Sciences (FAS) and the Faculty of Management Studies and Commerce (FMSC). The usage statistics available at the Ceylon Room from 2015 – 2019 were observed and analysed as primary data to study the user needs and requirements. Students (1139) and academics (121) of the university who visited the Ceylon Room between May and August 2021 were used for this study. Discussions with the Ceylon Room staff of the library were also important for the researchers to clarify the

usage of Ceylon Room materials by the user community. Structured interviews were conducted and online questionnaires were distributed among students and academic staff to monitor user needs and satisfaction with the CR collection. For this, 64 students and 58 academics responded. In addition, an open-ended question was included in the questionnaire to obtain users suggestions, comments and recommendations to explore the usage of the CR Collection. Descriptive statistics were used for analysis, and the results were presented in tabulated and graphical forms.

4. RESULTS AND DISCUSSION

In this study, the required information and data were collected by interviewing and distributing a questionnaire to both students and academics of the selected three faculties of the university who visited the Ceylon Room during the period from May to August in the year 2021. Additional data were taken from the existing library annual records. The questionnaire was used to gather data to get users' satisfaction about the CR Collection and its service.

4.1 Visiting Rate of the CR according to the Faculty

The students and academic staff of the three faculties who visited the Ceylon Room within three months were considered in this study. Table 01 demonstrates the total number of visitors, 53% for students and 47% for academics, respectively. All the responses were in a usable form for data analysis.

Table 01: Visiting Rate (As per the Faculty and User category)

User Category	No. of Visited Users			Total
	FHSS	FAS	FMSC	
Students	30 (25%)	12 (10%)	22 (18%)	64 (53%)
Academic Staff	27 (22%)	11 (9%)	20 (16%)	58 (47%)

According to Table 01, 25% of students and 22% of academics from the FHSS visited the Ceylon Room. Apart from that, the lowest visit rate was from FAS,

at 10% and 9%, by students and academics, respectively. In the FMSC, the rate of visiting students was 18%, and for academics, it was 16%.

4.2 Student Satisfaction with Ceylon Room Collection

Most of the rare collections in the libraries are considered 'closed access', meaning that the access is provided upon request. This is practiced as a security measure of the materials housed in those collections as sometimes, they contain scarce and valuable materials. Therefore, library staff who work in the Ceylon Room should be highly responsible and have an overall knowledge of the contents of the CR. It will also be helpful to increase user satisfaction by giving a better service.

Table 02: Student Satisfaction with Ceylon Room Collection

	No. of Students (Percentage)
Yes	51 (80%)
No	13 (20%)

The majority of the students (80%) mentioned that they were satisfied with the CR collection (Table 02). In addition, students stated that the library should acquire the latest resources in the relevant field more and increase the number of copies of the same title.

When data are analyzed faculty-wise, students of FHSS are marked with the highest rate of satisfaction with the CR Collection, and it is 39%. Meanwhile, 8% of FHSS students were dissatisfied with the CR Collection of the USJ library. The reason for this is that the collection of books related to certain subjects is not up-to-date. The rates of satisfaction and dissatisfaction against each faculty are shown in Figure 01.

Only 14% of students from the FAS have shown satisfaction towards the CR collection. On the other hand, the same faculty reported the least amount of dissatisfaction (3%). This shows that if more students were made aware of the existing resources in CR

Collection, the rate of satisfaction would be high.

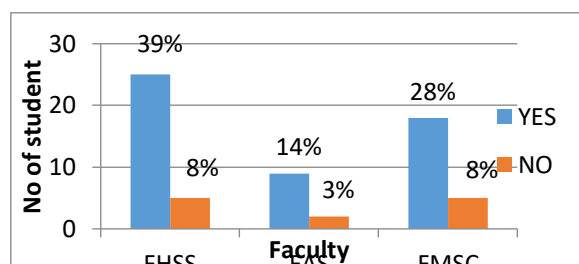


Figure 01 - Satisfaction of the Students towards Ceylon Room Collection by – Faculty

When considering the responses from students of three faculties, it can be seen that most students are satisfied with CR Collection. Also, the students who were dissatisfied with CR Collection had stated that CR Collection should be updated and students should be made better aware of the CR Collection.

4.3 Satisfaction of the Academic Staff with Ceylon Room Collection

Academic staff needs to support the process of selecting books for the CR collection since they are aware of new publications in their subject field. Moreover, they know about new publications by Sri Lankan authors in their particular subject area. It will help to maintain a rich updated collection to fulfill the user’s needs and requirements. Table 03 demonstrates the satisfaction of academic staff who visited the CR collection in the library of the University of Sri Jayewardenepura.

Table 03: Satisfaction of the Academic Staff towards Ceylon Room Collection

Responses	No. of Academic Staff	Response Percentage
Yes	31	53%
No	27	47%

Table 03 shows that 53% of academic staff members are satisfied with the existing CR Collection in the library, and 47% are dissatisfied. Observing these results, it can be seen that the gap is low between the number of satisfied and not satisfied academic staff members of the faculties.

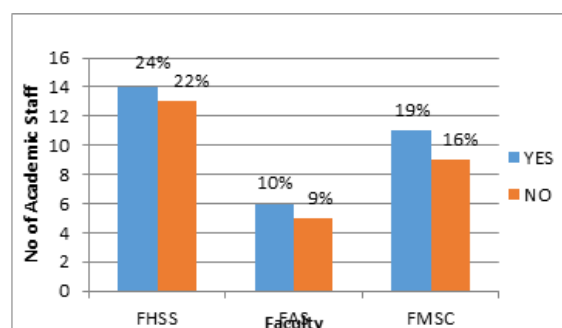


Figure 02 - Satisfaction of the Academic Staff with Ceylon Room Collection – by Faculty

When considering faculties, as shown in Figure 2, the gap is very low between the number of satisfied academic staff members and that of dissatisfied. Academic staff members who are satisfied with the CR Collection in FHSS, FAS and FMSC are 24%, 10% and 19%, respectively. Since a vast amount of publications contained in the Ceylon Room are more relevant to the field of Humanities and Social Sciences, there is a tendency for the readers of the FHSS to use the CR collection more. Therefore, the students and academic staff of the FHSS have a better satisfaction than the others with the CR collection. According to Figure 02, only 10% of academic staff members of FAS have shown satisfaction with the CR Collection. Implementation of FAS academic staff awareness programme should be ensured.

The CR Collection contains an extensive collection of locally published scientific research and conference papers. Therefore it is the responsibility of the library staff to raise awareness about the availability of science-based materials in the CR collection among staff and students of the FAS.

4.4 Ceylon Room Usage by Academic Staff 2015-2019

The CR collection is considered the heart of a library and one of the primary sources that to meet users’ specific information needs related to Sri Lanka. Therefore existing collections must be rich, updated, balanced, and relevant to the curricula of all faculties of the university. In addition, academic staff commented that the existing CR Collection would help them more effectively in their teaching, learning

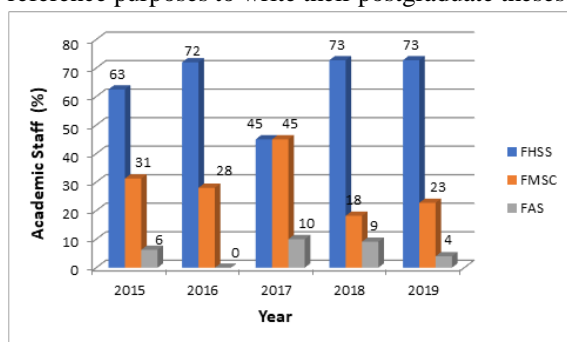
and research activities.

Table 04: Ceylon Room Usage by Academic Staff 2015-2019

Year	FHSS		FMSC		FAS	
	No of Academic Staff	Percentage	No of Academic Staff	Percentage	No of Academic Staff	Percentage
2015	20	63%	10	31%	2	6%
2016	18	72%	7	28%	0	0%
2017	9	45%	9	45%	2	10%
2018	16	73%	4	18%	2	9%
2019	16	73%	5	23%	1	5%
Total	79	65%	35	29%	7	6%

Source: Library Usage Records, 2021

According to Table 4, most of the academic staff members who used the CR Collection during 2015-2019 belonged to the FHSS. It is 65%. During that period, the least number of academic staff members who have used the Ceylon Room is from the FAS, and it is only 6%. Furthermore, the available statistics of the Ceylon Room shows that academic staff members of FAS have used CR Collection mainly for reference purposes to write their postgraduate theses.



Source: Library Usage Records, 2021

Figure 03 - Ceylon Room Usage by Academic Staff Members 2015-2019

The highest usage (63%) is by the academic staff members in FHSS in 2015, and in 2017, and the use of the CR collection by the academic staff of FHSS and FMSC has taken a similar value. It is 45%. During 2015-2019, the usage of the

CR Collection by the academic staff of FAS has shown a meagre value. During the year 2016, no academic staff member of FAS used the CR Collection. Only one academic staff member used it during 2019. In FMSC, The highest number (45%) was indicated in 2017, and the lowest 18% was in 2018.

According to Figure 03, the usage of CR Collection by FAS and FMSC also decreased because the library has subscribed to online full-text databases such as JSTOR, Research for life and citation database Scopus. Therefore the usage of printed materials by the above two faculties has reduced.

4.5 Ceylon Room Usage by Students 2015-2019

Most students come to the library to gain information about various subjects for their learning for research activities and to read books for entertainment. According to the theory of Rangnathan, "Books are for use." It means that readers must meet their needs in the library, and the library resources must meet the appropriate readers. Therefore, by having librarians perform both of these functions, the library can increase the use of the CR collection.

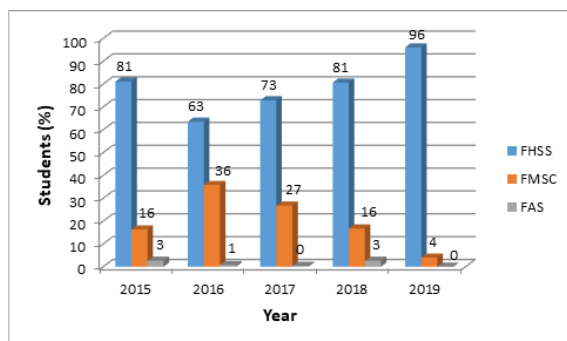
Table 05: Student Usage of Ceylon Room Collection

Year	FHSS		FMSC		FAS	
	No of Students	Percentage	No of Students	Percentage	No of Students	Percentage
2015	154	81.1%	31	16.3%	5	2.6%
2016	174	63.5%	98	35.8%	2	0.7%
2017	188	72.9%	69	26.7%	1	0.4%
2018	154	80.6%	32	16.8%	5	2.6%
2019	217	96%	9	4%	0	0%
Total	887	78%	239	21%	13	1%

Source: Library Usage Records, 2021

Table 05 shows that the highest usage of the CR Collection by students is from the FHSS, 78%. Whereas the least usage of the CR Collection by

students is from the FAS (1%). This may be because most of them are local publications related to Sri Lanka and do not directly match the subject disciplines of the FAS. In 2019, the highest usage can be seen from the students of FHSS. It is 96%, and table 05 shows that, none of the students in FAS have used the CR Collection during the same period.



Source: Library Usage Records, 2021

Figure 04 - Student Usage of Ceylon Room Collection

In 2015, the use of the CR collection by students of the FAS and FMSC was 16% and 3%, respectively. Therefore, it is necessary to introduce the resources and services available in the CR collection to the students of the above two faculties. Also, this study found that the students of these two faculties did not have enough knowledge about the CR Collection. Accordingly, it seems important to market the CR collection to the students of FAS and FMSC. Also it is necessary to improve on the staff's approach towards customers at the library, overall willingness to support, assistance to expose required resources in the library and support with queries related to their research component.

5. CONCLUSION AND RECOMMENDATIONS

The results of the study show that the academic staff and the students of the FHSS are comprehensively using the existing CR Collection of the library, and there is a low usage among the academics and students of the FMSC and the FAS. They use the CR Collection to refer to the theses and dissertations relevant to their subject disciplines in the Ceylon Room. Furthermore, the unawareness of the students

and academic staff of the FAS and FMSC about the existing resources in the CR Collection has been the reason for under-utilization. Hence, there is a need to promote the optimum use of the existing resources and services as some of the users are less aware of them.

Apart from that, inadequate time, limited infrastructural facilities, closed access and restrictions to the CR Collection and staff attitudes are indicated by respondents as problems. Therefore the library has a vital role in designing more efficient awareness and publicity programmes. Furthermore, students feel that recent publications of books are not adequately available in the collection.

According to the above findings, it can be recommended that the administrators should take steps to strengthen the services with which the users are satisfied, and concentrate on services that should be developed according to user requirements. To enrich user satisfaction, steps must be taken to resolve the identified problems. Also, the CR Collection should be continually re-evaluated to meet user requirements to support their academic activities.

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THE IMPACT OF BRAND POSITIONING AND BRAND KNOWLEDGE ON IMPULSIVE PURCHASING INTENTION WITH MEDIATING ROLE OF GREEN BRAND ATTITUDE: SPECIAL REFERENCE TO GREEN BRANDED PRODUCTS IN SRI LANKA

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ABSTRACT

The market for green products in Sri Lanka is small but rising. However, many green product producers adhere to the ideas of their Sustainable Living Plan (SLP) in order to manufacture green products that reduce emissions and stabilize natural ecosystems. Therefore, in order to provide their products a competitive edge in the eyes of consumers, green producers use green brand positioning tactics. The study's primary objective was to determine how brand positioning techniques and brand knowledge about green products influence the brand attitude and impulsive purchasing intention of consumers. This research study deployed a quantitative method of conducting interviews by developing a structured questionnaire. Multistage convenience sampling technique was deployed due to unavailability of an official data source on green product consumers. Moreover, data were collected from the green market places in Colombo, Kandy and Matara districts where the green products are available especially in supermarkets (Keells, Cargills) and green shops (Good Market). Accordingly, 300 responses were analyzed using SPSS software. Multiple regression analysis, correlation analysis and Hayes process Macro method were used to test the hypotheses. The findings showed that green brand positioning, brand knowledge, and brand attitude have a favourable influence on consumers' impulsive inclinations to buy green products. The findings also suggest that having a proper understanding of green brands will influence consumer sentiments towards green brands. The study states that green product marketers might further enhance green brand positioning by emphasizing the importance of a green product attribute to draw in large numbers of customers and to persuade them to make impulsive green purchases.

KEYWORDS: Green Brand attitude of the consumer, green brand knowledge, green brand positioning, green product impulsive purchase intention.

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1. INTRODUCTION

Environmental contamination can be considered as a big issue that is yet to be addressed. Worldwide manufacturing activities cause hazardous environmental pollution (Chen, 2011). Businesses are rapidly investigating and researching new ways, generating new concepts, and preparing new strategies in order to position their green brands as conforming to corporate social responsibility in environmental protection, which consumers can remember, and to keep them competitive in the market. Nowadays, many businesses readily recognize environmental preservation as a societal obligation. By developing an eco-friendly lifestyle system that illustrates that the entire life cycle of a product, from material acquisition through production, sales, and consumption, trash disposal, the company exhibits its care for environmental protection. (Wu and Chen, 2014). Green brand can be described as a specific collection of brand features which have numerous benefits related to minimizing the brand's environmental impact by providing environmental benefits and attracting consumers to purchase green products (Lidia and Lisboa, 2017).

In order to enhance the purchasing intention for green brands offered by companies, Chen and Chang (2012) contend that businesses must concentrate on declining the risk that consumers have regarding green brands by providing trustworthy information to help establish consumer trust and also enhance consumers' perceptions of the advantages of green brands. Businesses that desire to embrace eco-friendly or "going green" activities can utilize green marketing techniques to generate and promote any engagement aimed at meeting customer expectations or needs (Thogersen et al., 2015). Many multinational corporations in Sri Lanka collaborate closely with their customers to lessen environmental effect by providing eco-friendly products and engaging customers in environmental campaigns. Studies in literature have found green marketing in different countries relevant to the branding of green

products and green buying behaviour (Suki,2016 Huang et al., 2014; Chen et al., 2020; Chin et al., 2019; Thao et al., 2020; Wang et al., 2019). More importantly, Zhou et al. (2020) further stressed the need of more studies to recognize the impact of brand knowledge on green purchase intentions. However, there is a significant knowledge gap remaining in literature since none of them have directly focused on impulsive purchasing. Impulsive purchasing differs from other purchasing perspectives and this study aims how green consumers can be attracted towards impulsive purchasing though brand positioning strategy and brand knowledge. Further, mediating role of attitude towards the brand is tested by minimizing the knowledge gaps provided in the literature. Accordingly, research objectives were developed as follows.

1.1 Research Objectives

- I. To identify the impact of green brand positioning on green brand impulsive purchasing intention.
- II. To identify the influence of brand knowledge on green brand impulsive purchasing intention
- III. To assess the effect of green brand positioning on attitude towards green brand
- IV. To explore the impact of brand knowledge on attitude towards green brand
- V. To work out the impact of brand attitude on green brand impulsive purchasing intention
- VI. To identify the mediating role of attitude towards green brand.

2. LITERATURE REVIEW

Green marketing is a process for creating a marketing mix that takes advantage of shifts in consumer perceptions of eco-friendly goods and services by modifying goods, packaging, and production techniques to be more eco-friendly in order to meet and satisfy consumer needs, minimize adverse environmental effects, and encourage consumers to be more concerned about the environment (Yusiana and Widodo, 2015).The term "Green Brand" refers to

a certain set of brand characteristics that have the advantage of reducing the brand's environmental effect and imply that the product will be eco-friendly. (Lidia and Lisboa, 2017; Darhlstorm, 2011). More significantly, Huang et al. (2014) indicate in their research that a number of characteristics such as green brand positioning, attitude toward green brands, and green brand knowledge, have an impact on green brands consumption.

2.1 Green Brand Positioning and Impulsive Purchase Intention

Green brand positioning refers to how a company positions its eco-friendly products to best appeal to consumers. Consumers who have previously purchased eco-friendly products and who are aware of environmental issues tend to be more willing to buy eco-friendly products because the company actively promotes its green brand, which gives it a competitive advantage in the eyes of customers (Lin and Chang, 2012; Huang et al., 2014). Suki (2016) explained significant impact of ecofriendly products on purchase intention. Accordingly, the 1st hypothesis can be developed as follows:

H1-Green Brand Positioning has a significant impact on impulse purchasing intention of Green Products

2. 2 Green Brand Knowledge and Green Product Purchase Intention

According to Suki (2016), Green brand knowledge offers consumers with information about a product's distinctive brand qualities as well as its overall environmental benefits. Brand awareness and brand image are the two categories of brand studies in literature that have shown that brand knowledge can influence both buying intention and actual purchase intention. (Yadav and Pathak, 2016; Chen and Chang, 2012). According to Huang et al. (2014), customers have a strong desire to buy and consume green products if they have superior environmental awareness and attitudes toward green companies. Suki (2016), Huang et al. (2014), and Chin et al. (2019) discovered that knowledge about the green brand has a favourable and significant effect on green

product purchase intention. Based on the previous literature, the following hypothesis can be developed:

H2- Green brand knowledge has a positive and significant impact on green product purchase intention.

3. 3. Green Brand Positioning and Attitude towards Green Brand

According to several research, customers have become more environmentally conscious and have changed their perceptions of eco-friendly brands as a result of becoming aware of businesses' admirable environmental efforts (Becker-Olsen, Cudmore, & Cudmore, 2006). Green brand positioning, according to Patrick, Ibanez, and Sainz (2005), may influence consumers' perceptions of green brands favourably. According to Mostafa's 2009 study, consumers who had a favourable attitude toward eco-friendly goods were more likely to choose eco-friendly brands while making purchases. Accordingly, this research study suggests the below mentioned research hypothesis

H3- Green brand positioning has a positive and significant impact on green product impulsive purchase intention.

2.4. Green Brand Knowledge and Attitude toward Green Brand

According to Oliver and Lee (2010), consumer cognition, which is involved in total customer evaluation, comprises relevant prior experience as well as present brand knowledge. The majority of cognition-focused green marketing studies have discovered that knowledge about the brand and brand awareness can have a significant impact on consumers' attitude about the environment (Mostafa, 2007). Furthermore, Mostafa (2007) asserts that perceived brand knowledge is a great indicator of eco-friendly favourable attitudes, meaning that high awareness and positive brand image might enhance customer brand attitudes. According to Suki (2016) and Huang et al. (2014), green brand knowledge has a favourable and significant influence on attitudes toward green brands. Based on the data obtained in

the literature, a hypothesis can be constructed as follows:

H4.- Knowledge about the green brand has a positive and significant effect on attitude toward green brands.

2.5. Attitude towards the Green Brand and Purchasing Intention of Green products

Felix and Braunsberger (2016) assert that consumer attitudes about the environment frequently have an impact on purchasing decisions. According to Schiffman and Wisenblit (2014) and Thogersen et al. (2015), the most important factors that effect on customer attitudes and their propensity to purchase eco-friendly goods are positive feelings and images. Additionally, consumers who have a favourable intention towards eco-friendly items have a larger propensity to purchase these items by referring to eco-friendly businesses (Mostafa, 2007). According to Huang et al. (2014), Consumers' attitudes regarding green companies affect their propensity to buy eco-friendly goods. Consumers who have a positive brand perception are more likely to be inclined to buy green products. In accordance with Suki (2016), Yadav and Pathak (2016), and Huang et al. (2014), one's attitude towards green companies has a favourable and significant impact on one's inclination to buy green products. Based on the previous literature, the following hypothesis can be developed:

H5.- Attitude towards green brand has a positive and significant effect on the intention of purchasing green products.

2.6. Mediating role of attitude towards green products (ATGP) between Brand positioning and Impulsive purchasing intention

Few studies in the literature have focused on the mediating role of attitude towards green products, and it is viewed as a significant component by a few studies, while many studies have concentrated on the casual link between these variables. This variable has been identified as a mediator in a number of research

studies related to green products (Chu, 2018; Kautish et al., 2019; Sheeraz et al., 2016; and Najmi et al., 2012). More crucially, Wang et al. (2022) and Chen et al. (2020) stressed the significance of attitude towards brand in mediating the relationship between brand positioning and purchase intention. However, none of the studies in literature have examined the effect of attitude towards the green brand in mediating the relationship between brand positioning and impulsive purchasing intention since impulsive buying is a sort of addictive behavior and it was critical to examine how brand attitude influences brand positioning and impulsive purchase. Accordingly, based on the past facts, the current study develops the hypothesis using the attitude towards green products as a mediator. As per the above, the current research study suggests the following hypothesis.

H6.- Attitude towards green products mediates the relationship between brand positioning and impulsive purchasing intention.

2.7. Mediating role of attitude towards green products (ATGP) between Brand Knowledge and Impulsive purchasing intention

According to Noor et al. (2012), considerable knowledge would impact on someone's mind and it was discovered that customers with a proper brand knowledge had a bigger influence on their attitude toward the brand than consumers with a low level of brand awareness. This is also seen in the study by Yeoh and Paladino (2008), which shows that green product attitudes partially mediate the association between brand knowledge and green product purchasing intentions. They discovered that attitude towards the relationship between environmental concerns and green goods purchase had a full mediation impact. Moreover, Aman et al. (2012) stated that having brand knowledge will alter or mediate consumers' intention to buy green items. By the above review, a hypothesis can be developed as follows:

H7.- Attitude towards green products mediates the relationship between brand knowledge and impulsive

purchasing intention.

3. METHODOLOGY

The present study concentrated on observing how the brand positioning and brand knowledge influence on attitude towards brand and impulsive purchasing intention. Here, the researcher assumes that attitude towards brand work is a mediator between independent variables and the dependent variable. This research study falls under positivistic research philosophy and deductive approach, and it uses quantitative methods to assess reality using reliable instruments used by earlier researchers. Moreover, cross sectional data are utilized for this study. Finding a sample that accurately reflects the entire population of Sri Lankan customers who buy green brands was a difficult task for the study. There is no official database that compiles a list of people who buy green brands. As a result, the study used a multistage convenience sampling technique to choose the sample because food customers might be found throughout the entire nation.

First, districts were chosen randomly. Accordingly, three districts were chosen, namely Colombo, Matara and Galle. One hundred (100) customers who come

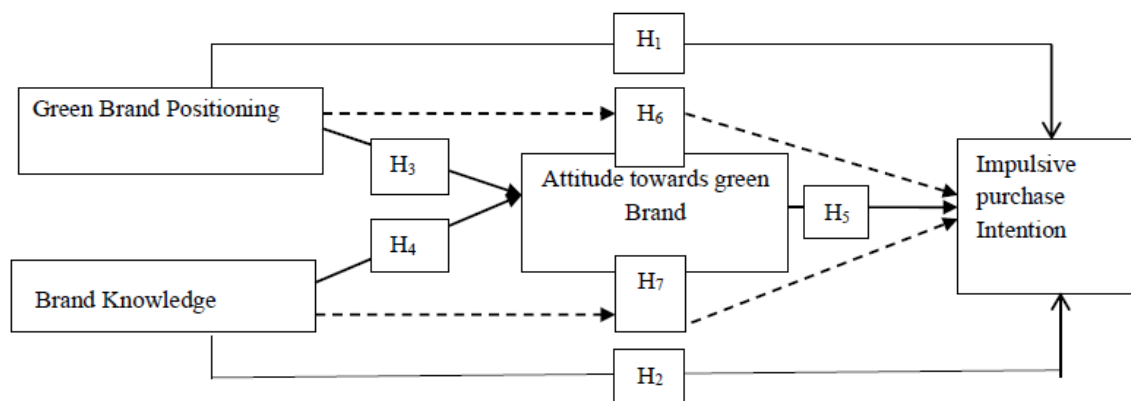
to Green shops (Good Market) and Supermarkets (Keels) in each district were interviewed, and it was done using convenience sampling. This study was primarily concerned with gathering primary information from customers using face-to-face interviews and a pre-designed structured questionnaire. The questionnaire was enhanced by adopting two items used by previous researchers to measure the main variables. The study used four indicators to measure brand knowledge and brand positioning. Additionally, the study used four indicators to measure attitude towards green brand and five indicators to measure impulsive purchasing intention.

4. ANALYSIS AND RESULTS

Test of validity

Validity indicates that the concepts and items referred to measure the variables. The test's validity might be considered to be its most crucial component in terms of test quality. Therefore, assessing validity is crucial and necessary before going through additional analytical procedure. analytical procedure.

Conceptual Framework of the Study



2.1 Conceptual Framework Developed by the Author

Table 1: Test of Validity (Source: Compiled by the Author)

Variable	Chi-square Value	Significance >0.05	KMO Value >0.5	Composite Reliability >0.7	Average Variance Extracted (AVE) >0.5	Discriminant Validity			
						Green Brand Positioning	Brand Knowledge	Attitude towards green brand	Impulsive Purchasing intention
Green Brand Positioning	208.913	.000	.760	.702	.648	.804			
Brand Knowledge	323.649	.000	.698	.721	.592	.466	.769		
Attitude towards brand	287.353	.000	.716	.890	.729	.328	.478	.853	
Impulsive purchasing intention	692.259	.000	.873	.809	.675	.518	.538	.337	.821

Table 1: Test Validity

The sample adequacy for all the variables was determined in this instance, all the coefficients are higher than zero ($P > 0.05$), and convergent validity was utilized to assess the validity. Since (Composite Reliability > Average Variance Extracted) and the shared over values are lower than the (AVE), discriminant validity was also guaranteed. The diagonal values which are highlighted to represent the AVE's square root are higher than the correlation between latent variables in other cells.

Table 2: Test of Reliability (Source: Compiled by author)

Variable	Cronbach's Alpha	Comment
Green Brand Positioning	0.726	Accepted
Brand knowledge	0.769	Accepted
Attitude towards green brand	0.815	Accepted
Impulsive Purchasing intention	0.839	Accepted

Table 3: Correlation Table (Source: Compiled by author)

Notes: **. Correlation values are significant at the 0.01 level (2-tailed).

		Brand Positioning	Brand Knowledge	Attitude towards Green Brand	Impulsive Purchase
Green Brand Positioning	Pearson Correlation	1	.466**	.328**	.518**
	Sig. (2-tailed)		.000	.000	.000
	N	300	300	300	300
Brand Knowledge	Pearson Correlation	.466**	1	.478**	.538**
	Sig. (2-tailed)	.000		.000	.000
	N	300	300	300	300
Attitude towards green brand	Pearson Correlation	.328**	.478**	1	.337**
	Sig. (2-tailed)	.000	.000		.000
	N	300	300	300	300
Impulsive Purchasing intention	Pearson Correlation	.518**	.538**	.337**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	300	300	300	300

Table 2: Test of Reliability

Since each and every variables had a Cronbach Alpha (α) value greater than 0.7, the reliability was guaranteed. As a result, it satisfied the requirement for measuring internal consistency. Therefore, it ensured the internal consistency of the measurement variables.

Table 3: Correlation Table

According to the details in Table 3, all independent factors have a positive relationship with the attitude towards green brand and the impulsive purchase intention, where the brand positioning and brand knowledge have positive correlation of 0.518 and 0.538 respectively with impulsive purchase. Whereas it illustrates that brand positioning and brand knowledge have positive correlations, respectively 0.328 and 0.478 with attitude towards green brand.

Simple linear Regression Analysis

Simple linear regression was used in order to testify the direct impact.

H1- Green Brand Positioning has a significant impact on the impulse purchasing intention of green products

Table 4: Model Summary
Source: Compiled by Author

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.634 ^a	.378	.356	.86499
a. Predictors: (Constant), Green Brand Positioning				

Table 4: Model Summary

The above model (4) shows the summary of simple

linear regression analysis. The explanatory power (R²) illustrates the degree to which extent the variance of the dependent variable is explained by the independent variable. Looking at adjusted R², it can be concluded that 38% of the variance of the dependent variable, impulsive purchasing intention, is explained by the independent variable of brand positioning.

Table 5: coefficient Table
Source: Compiled by author

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.645	.260		14.217	.000
	Green Brand	.172	.027	.168	15.343	.000
a. Dependent Variable: impulsive purchasing intention						

Table 5: coefficient Table

(β) Coefficient brand positioning is 0.168. It reveals that increasing one unit of brand positioning reasons increasing impulsive purchase in 0.168 units whereas other independent variables remain constant. The alpha value is 0.000 at 95% of confidence level. The model can be indicated as $Y=1.645+0.168(x1)$

H-2 Brand Knowledge has a significant impact on impulsive purchasing intention.

Table 6: Model Summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
2	.423 ^a	.288	.286	.76799
a. Predictors: (Constant), Brand Knowledge				

Table 6: Model Summary

Table 6 above illustrates that (R²) is a measure of how much of the variance in the dependent variable can be attributed to the independent variable. The independent variable, brand knowledge accounts for 28% of the variance in the dependent variable, according to the adjusted R².

Table 7: coefficient Table

In accordance with the coefficients table (7), the 2nd alternative hypothesis is significant since it proves that the P (alpha) value of brand knowledge has no effect on impulsive purchasing intention. Accordingly, the model can be written as $Y=2.6413 + (-0.2671) (x_2)$.

H-3 Green brand positioning has a significant impact on attitude towards Brand

Table 7: coefficient Table
Source: Compiled by author

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
2	(Constant)	2.613	.200		13.217	.000
	Brand knowledge	-.282	.037	-.2671	13.343	.012

a. Dependent Variable: impulsive purchase intention

Table 8: Model Summary

In the table 8, (R²) illustrates the degree to which extent the variance of the mediating variable is explained by the independent variable (1). As per the adjusted R², it can be elaborated that 47% of the variance of mediating variable, attitude towards

brand is explained by independent variable (1) Green brand positioning.

Table 8: Model Summary
Source: Compiled by author

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
3	.421 ^a	.488	.475	.72499

a. Predictors: (Constant), Green Brand Positioning

Table 9: coefficient Table

The table 9 elaborates that the 3rd alternative hypothesis is not significant since it does not prove that the P value of green brand positioning, , which is 0.641, is lower than 0.05. Accordingly, it is concluded that green brand positioning has no significant positive impact on attitude towards the green brand. Accordingly, H3 is rejected.

H-4- Brand Knowledge has a significant impact on attitude towards Brand.

Table 9: coefficient Table

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
3	(Constant)	1.945	.200		13.217	.000
	Green Brand Positioning	.698	.037	.623	13.343	.641

a. Dependent Variable: customer Loyalty

Table 10: Model Summary

In the table 10, (R²) illustrates the degree to which

extent the variance of the dependent variable is explained by the independent variable. Considering the adjusted R2, it can be concluded that 41% of the variance of mediating variable, attitude towards the brand, is explained.

Table 10: Model Summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
4	.713 ^a	.328	.416	.62799
a. Predictors: (Constant), Brand Knowledge				

Table 11: coefficient Table

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
		4	(Constant)	3.645		
	Brand knowledge	.215	.057	.208	13.343	.021
a. Mediating Variable:						

Table 11: coefficient Table

According to the coefficients table (11), the 4th alternative hypothesis is significant since it proves that the P value of brand knowledge is lower than

0.05 and which is 0.021. Accordingly, it is concluded that brand knowledge has a positive impact on attitude towards the green brand. Accordingly, the model can be written as $Y=3.645 + (-0.208) (x_4)$

H-5 Attitude towards the green brand has a positive impact on impulsive purchase intention

Table 12: Model Summary

In the table 12, (R2) illustrates the degree to which extent the variance of the dependent variable is explained by the mediating variable. Looking at the adjusted R2, it can be decided that 45% of the variance of the dependent variable, impulsive purchasing intention is defined by the mediating variable.

Table 12: Model Summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
5	.753 ^a	.488	.456	.72659
a. Predictors: (Constant), Brand Knowledge				

Table 13: coefficient Table

In the coefficients table (13), the 5th alternative hypothesis is significant since it proves that the P value of attitude towards the brand, which is 0.012, is less than 0.05. Accordingly, it is concluded that attitude towards the green brand has a positive impact on impulsive purchase intention. Accordingly, the model can be written as $Y=2.645 + (-0.597)(x_5)$.

Table 13: coefficient Table

Coefficients						
Model	Unstandardized Coefficients		Standardized Coefficients		t	Sig.
	B	Std. Error	Beta			
5	(Constant)	2.645	.200		13.217	.000
	Attitude towards the Brand	.597	.037	.597	13.343	.034

a. Dependent Variable: Impulsive purchasing intention

Testing the mediating effect

The Hayes process-macro method was used to testify the mediating effect

H6-Attitude towards green brand is a mediator which connects green brand positioning and impulsive purchasing intention.

Table 14: Total Effect Model

Total effect model depicts in table 14 that the R square is 15%, and it indicates that 15% of the variance of dependent variable is explained by the independent variable (1), brand positioning and the mediating variable, attitude towards the brand.

Table 15: Total Model

The Total model (15) indicates that the standardized coefficient of brand positioning (1st Independent Variable) is 0.1685, which lies between the lower level confidence interval, 0.2658 and upper level of 0.1654, and this is significant since p value is less than 0.05. However, the standardized coefficient of brand attitude is 0.2643, which does not lie between 0.1511 and 0.3860 and where the P value is 0.1930, which is higher than 0.05. Hence, it can be concluded that brand attitude is not a significant factor, and it cannot work as a mediator between brand positioning and impulsive purchase.

Table 14: Model Summary

R	R-sq.	MSE	F	df1	df2	p
3902	.1523	.3787	75.2575	1.0000	419.0000	.0000

Outcome Variable: Impulse purchase Intention

Table 15: Total Model

	Coefficients	se	t	p	LLCI	ULCI
constant	1.3002	.1304	9.3621	.0000	.9648	1.4777
Brand Position	.1685	.0495	3.4044	.0000	.2658	.1654
Brand Attitude	.2685	.0597	4.4948	.1930	.1511	.2456

Notes: **. The standardized coefficients of Brand Positioning is.1630. The standardized coefficients of Brand Attitude is.2643

Total, Direct, and Indirect Effects of X on Y

Table 16: Total effect of X on Y

The total effect table (16) indicates the cumulative effect of direct and indirect effect, and it lies between the upper level, 0.4877 and lower level, 0.3075 confidence intervals, and it is significant since p value is less than 0.05.

Table 16: Total effect of X on Y

Effect	se	t	p	LLCI	ULCI	c cs
.3976	.0458	8.6751	.0000	.3075	.4877	.3902

Table 17: Direct effect of X on Y

A direct effect of x on y in table 17 depicts that brand positioning has a (0.1685 /0.3967) 100=42% effect on the dependent variable, impulsive purchase.

Table 17: Direct effect of X on Y

Effect	se	t	p	LLCI	ULCI	c' cs
.1685	.0495	3.4044	.0007	.0712	.2658	.1654

Table 18: Indirect effect(s) of X on Y:

The indirect effect of x on y in table 18 depicts that attitude towards the brand cannot work as a mediator between brand positioning and impulsive purchase since it does not lie between the upper level of bootstrapping and the lower level of bootstrapping. Moreover, it determines the indirect effect is not significant since it is not between the values of upper level and lower level of bootstrapping.

H7-Attitude towards green brand is a mediator which connects brand knowledge and impulsive purchasing intention.

Table 18: Indirect effect(s) of X on Y:

	Effect	Boot SE	Boot LLCI	Boot ULCI
Brand position	.2691	.0408	.1538	.2432

Table 19: Total Effect of X on Y Model Summary

R	R-sq.	MSE	F	df1	df2	p
.1611	.0259	.4351	11.1586	1.0000	419.0000	.0009

Source: Outcome Variable: Impulse purchase Intention

Table 19: Total Effect of X on Y

Total effect model depicted in table 19 indicates that the R square is 25%, and it indicates that the 25% of the variance of dependent variable is explained by the independent variable (2), brand knowledge and through the mediating variable, attitude towards the green brand.

Table 20: Total Model

The coefficient table (20) indicates that the standardized coefficient of brand knowledge is 0.3476, which lies between the lower level confidence interval 0.1567 and upper level of 0.4121, and this is significant since p value is less than 0.05. Accordingly it indicates a negative relationship.

Table 20: Total Model

	coeff	se	t	p	LLCI	ULCI
constant	1.7417	.1768	9.8488	.0000	-1.3941	2.0893
Brand knowledge	-.2826	.0547	3.3405	.0009	-.0752	.3901
Brand Attitude	.3476	.0496	4.6785	.0043	.1567	.4121

Notes: **. The standardized coefficients of Brand knowledge is .26171 The standardized coefficients of Brand Attitude is .3345

Source: compiled by the Author

TOTAL, DIRECT, AND INDIRECT EFFECTS OF X ON Y Total effect of X on Y

Table 21: Total effect of X on Y

Effect	se	t	p	LLCI	ULCI	ccs
.1826	.0547	3.3405	.0009	.0752	.2901	.1611

Source: Compiled by the Author

Table 21: Total effect of X on Y

The total effect table (21) indicates the cumulative effect of direct and indirect effect and it lies between the upper, 0.2901 and lower level, 0.0752 confidence intervals, and it is significant since p value is less than 0.05. However, the total effect is positive though the direct effect is negative.

Table 22 Direct effect of X & Y

Effect	se	t	p	LLCI	ULCI	c' cs
-.1116	.0533	-2.0917	.0371	-.2164	-.0067	-.0984

Table 22: Direct effect of X on Y

Direct effect of x on y in table 22 depicts that brand knowledge has a 27% effect on the dependent variable, impulsive purchasing intention. Accordingly, the effect is negative.

Table 23: Indirect effect of X on Y

	Effect	Boot SE	Boot LLCI	Boot ULCI
knowledge	.2942	.0434	.2103	.3796

Source: compiled by the Author

Table 23: Indirect effect of X on Y

Indirect effect of x on y in table 23 depicts that brand knowledge has a 73% indirect effect (brand knowledge through attitude towards brand on impulsive purchase) on the dependent variable, impulsive purchasing intention. Accordingly, it concludes that attitude towards brand is working as a mediator which connects brand knowledge and impulsive purchasing intention. More importantly, it concludes that mediating variable, attitude towards brand is a strong mediating variable since it completely changes the negative direct effect into a positive total effect with the power of mediating variable.

Table24: Completely standardized indirect effect(s) of X on Y:

	Effect	Boot SE	Boot LLCI	Boot ULCI
Similar	.2595	.0404	.1820	.3409

Notes: **, Level of confidence for all confidence intervals in output: 95. %
Number of bootstrap samples for percentile bootstrap confidence intervals: 5000

Table24: Completely standardized indirect effect(s) of X on Y:

As indicated by the table (24) brand knowledge has standardized effect of 0.2595 which accounts for 73% indirect effect (brand knowledge through attitude towards brand on impulsive purchase) on the dependent variable, impulsive purchasing intention.

Table25: Summary of the Hypotheses Testing

Hypotheses	Hypotheses	P value	Accept or Reject	Effect Negative or Positive
Brand Positioning → Impulsive Purchase	H ₁	0.000	Accept	Positive
Brand Knowledge → Impulsive Purchase	H ₂	0.012	Accept	Negative
Brand Positioning → Brand Attitude	H ₃	0.641	Accept	Positive
Brand Knowledge → Brand Attitude	H ₄	0.000	Accept	Positive
Brand Attitude → Impulsive purchase	H ₅	0.034	Accept	Positive
Brand Positioning → Brand Attitude → Impulsive purchase	H ₆	0.193	Reject	-
Brand Positioning → Brand Attitude → Impulsive purchase	H ₇	0.004	Accept	Positive

5. RESULTS AND DISCUSSION

When compared with the existing literature, the findings suggested from our study slightly differ. The results of our study clearly show that brand positioning affects impulsive purchases in a major way, which is supported by earlier research studies. According to Liao et al. (2020), customers are more likely to acquire green products as a result of the strong focus placed on green brand positioning.

Suki (2016) reported that purchasing eco-friendly products reflects that consumers feel responsible for the environment and explained that the probability of consumers' purchasing green products is totally dependent on the use of consumer products and their awareness of the green brand positioning in the market. Moreover, research conducted by Huang et al. (2014) and Chin et al. proclaimed that green brand positioning considerably impacts on the purchase intention of green items. Based on the study findings, it can be stressed that when positioning a brand as an eco-friendly brand it will tend to increase the green purchase intention impulsively among its customers.

As per the above research model, green brand knowledge is the variable that has the only negative impact on impulsive purchasing intention. Accordingly, this factor that can influence negatively for consumers in impulsively purchasing green products. It implies that when consumers have a good knowledge about the particular product that would not influence on impulsive purchase since enough knowledge would generate rational thinking and that would not lead for impulsive stimulations. Accordingly, higher the knowledge of the brand consumers will go for rational purchasing rather than going for impulsive purchasing. However, this is contradictory with the findings of Huang et al., 2014; Suki, 2016; Chin et al., 2019 and Zhou et al., 2020 since all of them have revealed that brand knowledge positively impacts on the purchasing intention. However, Siyal et al. (2021) stated that when consumers have more detailed information about eco-friendly products, consumers could direct their considerations in the purchasing decision-making

process, which implies that consumers will follow consumer decision making process rather than quick stimulating purchases.

The third hypothesis of our study proved that brand positioning does not have a significant impact on attitude towards the green brand, and it is contradictory to the literature. Accordingly, Aulina & Yuliati (2017) found that brand positioning negatively impacts on attitude towards brand. On the contrary, literature reveals that higher the brand positioning, higher the positive effect on brand attitude. Patrick, Ibanez, and Sainz (2005) also argued that green brand positioning has a positive effect on consumers' attitudes towards green brands. Indeed, the study of Mostafa (2009) showed that a positive attitude towards green products tended to purchase green products by referring to the brands with green positioning.

Additionally, the fourth hypothesis was justified since it was found that brand knowledge had a positive impact on attitude towards the green brand. More importantly this was determined by the past findings. Most of the green marketing studies have focused on cognition and have shown that brand knowledge and awareness can significantly influence consumers' brand attitudes (Mostafa, 2007). Suki (2016), Yadav and Pathak (2016) and Huang et al. (2014) found brand knowledge has a positive and significant effect on attitude towards the green brand.

The 5th hypothesis of our study suggested that attitude towards the brand positively affects impulsive purchase, and it is parallel with the literature. Accordingly, Mostafa (2007) in Huang et al. (2014) who concluded that consumers' attitude has an important role in forming behavioural intention, and consumers with high level of attitude towards green products would form a strong desire towards green purchase intention.

More interestingly, the results of our study determine that the attitude towards the green brand cannot work as a strong mediator between brand positioning and the impulsive purchase that does not agree with the exiting findings stated by Wang et al. (2022) and

Chen et al. (2020). They stated that brand positioning and attitude towards green products impact on impulsive purchase. However, none of the research studies has measured the indirect effect generated through attitude towards green brand. In fact, this research further determines by testing that indirect effect cannot be generated through attitude toward brand on impulsive purchase.

The attitude towards the brand mediates the brand knowledge and the impulsive purchase intention. More interestingly, this is somewhat slightly differ and also being comparable to the prior ones. Accordingly, Our findings are justified by the Aman et al. (2012) and Yeoh and Paladino (2008) since these studies reveals the mediation effect of attitude towards the brand between brand knowledge and impulsive purchase of green products. Moreover, Indriani, Ida & Hadiwidjojo, D. (2019) also justified our results by emphasizing that attitude towards the brand mediates the brand knowledge and the impulsive purchasing intention.

6. CONCLUSION

This study's ramifications are classified into two categories: practical and theoretical consequences. Theoretical implications for future researchers connected to the evolution of study outcomes and it is related to brand knowledge, attitude towards green products, and green product impulse purchase intention. The study would have some practical applications such as managerial contributions to organizations regarding marketing and branding techniques to gain consumer purchasing interest. Based on this finding, businesses must pay close attention to how they place their brands in the minds of consumers through an integrated and focused marketing communication strategy. Green brands must communicate environmentally related messages to targeted consumers in ways that pique consumers' interest in learning more about the brand's green efforts, and then green brands must provide ways for consumers to engage in learning more about the brand and its products. Educating consumers on the natural components that the brand usually uses in its products is one of the things that the corporation may

have to undertake. Using social media and store displays would be an excellent strategy for brand positioning and refining consumer attitudes about the brand.

Limitations and Future Research Suggestions

Future research will be able to investigate and widen the scope of this study by taking into consideration other factors that influence impulsive purchasing intentions for green items. Furthermore, because there is no comprehensive list of green product users in Sri Lanka, the scope of this study is limited, and convenience sampling was used. The research data were collected over a specified time period (cross section), and it is anticipated that in the future, time series data will be used to build better research. Furthermore, future studies should largely focus on diverse consuming behaviour patterns such as compulsive purchasing because this will provide better insight for both marketers and academics to acquire a full grasp of how consumers respond in various scenarios depending on the situation.

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A STUDY ON WORKLOAD OF A MEDICAL LINEAR ACCELERATOR AT A HIGH THROUGHPUT CANCER TREATMENT CENTRE IN SRI LANKA

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ABSTRACT

Radiotherapy bunker design depends on several factors, and among them, workload is one of the important factors. Workload is calculated from the radiation dose delivered at the isocenter. Due to the introduction of new radiotherapy treatment modalities and an increasing number of new cancer patients, there is a higher possibility to increase the workload. Therefore, this study aims to assess the workload of Varian linear accelerator vault at Apeksha Hospital, Maharagama. Data were collected from 1st of August 2020 to 30th November 2020. Dose delivered at isocenter from the 3D-CRT procedures with 6 MV and 15 MV photon energy, the IMRT procedures with 6 MV photon energy and the quality assurance (QA) procedures were collected from ARIA patient management system and transferred into Excel spread sheet for data analysis. The calculated weekly workload was 2326 Gy/week with a 43% contribution from the IMRT procedures with 6 MV, 39% contribution from the 3D-CRT procedures with 6 MV, 16% contribution from the 3D-CRT procedures with 15 MV and 2% contribution from physics workload (QA procedures). The evaluated workload is higher than the NCRP recommended workload of 1000 Gy/week. This study recommends for at least a one-year survey for more accuracy on workload assessment, and also to evaluate the use factor since most of the advanced radiotherapy treatment techniques use high number of monitor units which will increase the leakage radiation.

KEYWORDS: Workload, Linear accelerator, 3-dimensional conformal radiotherapy, Intensity-modulated radiotherapy, Quality Assurance procedures

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1. INTRODUCTION

Cancer is one of the leading causes of death and a major obstacle to increasing life expectancy in every country in the world. According to the GLOBOCAN report, 19.3 million new cancer cases and about 10 million deaths have been reported worldwide in 2020 (Sung et al., 2021). In Sri Lanka, 29604 new cases and 16691 deaths have been reported in 2020 (WHO, 2023). Radiotherapy is one of the major cancer treatment options and about 50% of cancer patients receive radiotherapy during their course of treatment as an integral part of treatment (Baskar et al., 2017, Ramanathan V, 2021). With the advent of Multileaf Collimators (MLCs), there are several advanced radiotherapy modalities currently available such as 3-dimensional radiotherapy (3D-CRT), intensity modulated radiotherapy (IMRT), image guided radiotherapy (IGRT), tomotherapy, volumetric arc therapy (VMAT) stereotactic body radiation therapy (SBRT), FLASH radiotherapy and stereotactic radiosurgery (SRS) (Ramanathan, 2017). Due to the evolving nature of radiotherapy treatment modalities, the structural shielding design of conventional radiotherapy bunker should be assessed according to the new workload and use factor of the radiotherapy equipment.

Radiotherapy bunker design and shielding are the very crucial part before installing new radiotherapy equipment. The aim of shielding is to limit the radiation exposure level to staff and public. When photon and neutrons are generated, the recommended quantity for shielding design is dose equivalent (H), which is defined as the product of absorbed dose and quality factor for particular ionizing radiation (ICRU, 1993). The recommended quantity for low linear energy transfer (LET) particles is air kerma (K_a) (NCRP, 2004). In addition, the recommended quantity for a person's radiation protection is the effective dose (E) which is defined as the sum of the weighted equivalent doses to specific organs or tissue (NCRP, 1993).

Workload is one of the indications of output radiation per week for external beam radiotherapy. Typically, 50 patients are treated with a medical linear accelerator during 8 hours per day. NCRP Report 49

(NCRP, 1976) suggests the workload of 1000 Gy/week for megavoltage facilities. It can be applied for dual energy linear accelerator also. NCRP Report 51 (NCRP, 1977) recommends 500 Gy/week for higher energies and remaining workload being contributed from electron therapy or low energy x-rays. Patient workload was traditionally calculated for conventional radiotherapy treatment. The introduction of advanced radiotherapy modalities such as IMRT, VMAT and Flattening Filter Free (FFF) has made some challenges on patient workload and use factors which are completely different from the conventional treatment. Therefore, this study aims to assess the patient workload for Varian Clinic 2300CD unit at Apeksha Hospital, Maharagama, Sri Lanka.

2. MATERIALS AND METHODS

In order to design the shielding structure for a modern linear accelerator installation, dose delivered at isocenter and leakage radiation which depends on delivered monitor units (MUs) need to be considered. This study mainly focuses on assessing weekly workload to compare with NCRP recommended weekly workload. It is a retrospective study. Data were collected from 1st of August 2020 to 30th November 2020 in the Varian Unit at Apeksha Hospital, Maharagama. In this study, 3D-CRT and IMRT treatments with 6 MV photon and 15 MV photon were included. Electron treatments were excluded. All the treatment data were accumulated from ARIA patient management system. The collected data were transferred to Excel spread sheet. In addition, all relevant quality assurance procedures which were performed during this data collection period were accumulated from the chief physicist of Apeksha Hospital. The data were analyzed using Microsoft Excel.

3. RESULTS

Figure 1 shows the treatment room layout for Varian linear accelerator at Apeksha Hospital, Maharagama. A total number of procedures which were performed by using 3D-CRT treatment technique with 6 MV photon energy during 4 months of workload survey

are shown in table 1. By using this treatment modality, a higher dose was delivered in September 2020 and also a maximum number of treatments were performed in September 2020. Looking at the IMRT procedures with 6 MV photon energy during this survey, a maximum number of procedures were performed in October 2020 but a higher dose was delivered at isocenter in September 2020. Considering the 3D-CRT treatment technique with 15 MV photon energy during this survey, a maximum number of procedures were performed in September 2020 and also a maximum dose was delivered at isocenter in September 2020. Figure 2 and figure 3 show the pie chart of total workload for 6 MV photon energy and 15 MV photon energy procedures.

Table 1: Total number of treatments and total dose delivered at isocenter with 6 MV 3D-CRT procedures.

Month	Total dose delivered at isocenter (cGy)	Number of treatments
August, 2020	544251.72	742
September, 2020	577595.86	842
October, 2020	164220.28	624
November, 2020	135562.91	541

Table 2: Total number of treatments and total dose delivered at isocenter with 6 MV IMRT procedures.

Month	Total dose delivered at isocenter (cGy)	Number of treatments
August, 2020	584667.02	548
September, 2020	694643.23	661
October, 2020	145698.78	706
November, 2020	98496.46	471

Table 3: Total number of treatments and total dose delivered at isocenter with 15 MV 3D-CRT procedures.

Month	Total dose delivered at isocenter (cGy)	Number of treatments
August, 2020	174388.14	492
September, 2020	270901.17	709
October, 2020	98529.34	513
November, 2020	61328.65	270

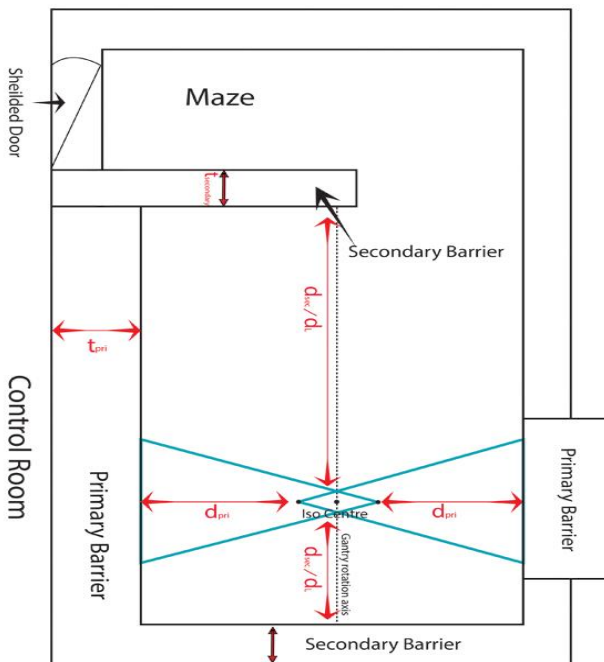


Figure 1: Treatment room layout of Varian linac vault at Apeksha Hospital.

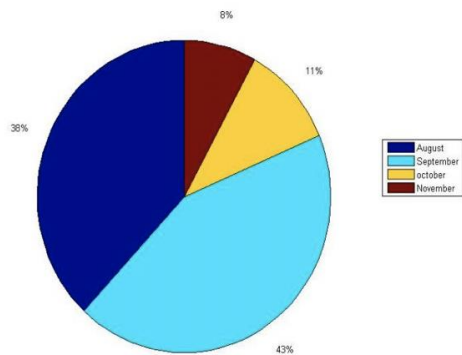


Figure 2: Total workload for 6 MV photon energy procedures for each month during the study period.

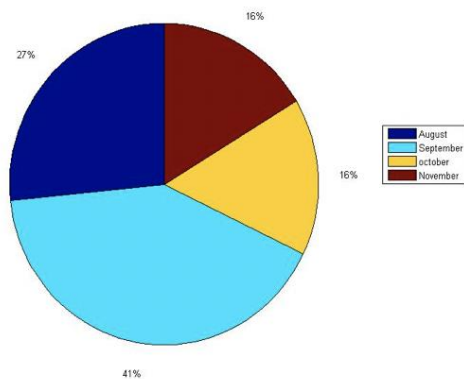


Figure 3: Total workload for 15 MV photon energy procedures for each month during the study period.

Shielding design goals, which are the practical values of a set of radiotherapy source or a single source, are evaluated at a reference point beyond a protective barrier. The shielding design goals are generally expressed as weekly values since workload for a radiotherapy source is traditionally used in a weekly format (NCRP, 2005). The calculated weekly workload for the 3D-CRT technique with 6 MV photon energy and 15 MV photon energy were 899.83 Gy/week and 384.32 Gy/week respectively. The estimated workload for IMRT treatment technique with 6 MV photon energy was 996.09. There is no workload for the IMRT treatment

technique with 15 MV photon energy. Workload for the quality assurance (QA) procedures were 2000 cGy/week for monthly QA procedures, and approximately 7125 cGy/week dose was delivered at isocenter for the daily QA procedures.

Overall weekly workload for the 3D-CRT, IMRT and QA procedures (physics workload) with 6 MV photon energy was 1918.97 Gy/week and the overall workload for 15 MV procedures was 407.37 Gy/week. Finally, the weekly workload including all procedures with both photon energy of 6 MV and 15 MV was 2326.34 Gy/week (see table 4 and 5).

Table 4: Average weekly workload for 3D-CRT and IMRT treatment procedures.

3D-CRT		IMRT	
Workload for 6 MV (Gy/week)	Workload for 15 MV (Gy/week)	Workload for 6 MV (Gy/week)	Workload for 15 MV (Gy/week)
899.83	384.32	996.09	0

Table 5: Average total workload for one week.

6 MV (Gy/week)	15 MV (Gy/week)
1918.97	407.37

4. DISCUSSION

This study aimed to assess the weekly workload of Varian Clinic 2300CD linear accelerator vault at Apeksha Hospital, Maharagama. The purpose of radiation shielding was to reduce the equivalent dose from source of radiation to point outside the room (Bunker) to a sufficiently low level of radiation. The required shielding was calculated based on the weekly workload of the machine, the distance from the source/isocenter to the point being shielded, modified by the fraction of time that the beam was pointed in that direction, and the fraction of the working week that the space was occupied.

This study only focused on weekly workload measurement since the introduction of advanced radiotherapy modalities has made some challenges on patient workload. The calculated weekly workload

for all treatment procedures of 3D-CRT planned with 6 MV photon energy (39% contribution), IMRT planned with 6 MV photon energy (43% contribution), 3D-CRT planned with 15 MV photon energy (16% contribution) and physics workload (QA procedures) (2% contribution) was 2326.34 Gy/week. But, NCRP Report (NCRP, 1976) suggests a weekly workload of 1000 Gy/week.

Ziad et al., 2017 did a 10-year survey of workload from 2006 to 2015 for 10 treatment vaults in USA. The dose delivered to isocenter in 2016 was (300±116) Gy/week. It was well below the NCRP recommended value. Another study was performed with 16 tomotherapy vaults in Korea. They have evaluated the weekly workload to be in the range of 600 to 14720 Gy/week. It indicates that new technology produces high workload. In the current study also IMRT treatment technique workload has a higher contribution (43%) than other treatment techniques.

In the current study, weekly workload was approximately 2326 Gy/week, which is a relatively higher weekly workload. The reasons for the higher weekly workload are the increasing number of new cancer cases that increases the number of treatment procedures per day (Ramanathan V, et al., 2022), the usage of advanced treatment modality of IMRT, and the availability of a limited number of linear accelerators (Ramanathan V, 2021). In Sri Lanka, 7 government hospitals and 2 private sector hospitals provide radiotherapy treatment facilities. Sri Lanka has only 0.93 megavoltage radiotherapy machines per one million people. It is very less comparing with International Atomic Energy (IAEA) recommendation of 4 to 8 radiotherapy centres per one million people (Ramanathan et al., 2022).

5. CONCLUSION

The calculated weekly workload was 2326 Gy/week with a 43% contribution from the IMRT procedures with 6 MV, 39% contribution from the 3D-CRT procedures with 6 MV, 16% contribution from the 3D-CRT procedures with 15 MV and 2% contribution from physics workload (QA procedures).

The evaluated weekly workload of Varian linear accelerator vault at Apeksha hospital was relatively high compared to NCRP suggested value of 1000 Gy/week. Since this study considered a survey of only 4 months, we recommend to perform at least a one-year survey for more accurate calculation of weekly workload. This study further recommends to evaluate the use factor since most of the advanced treatment techniques in radiotherapy use higher number of monitor units which will increase the leakage of radiation.

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DYNAMICS OF OPTIMAL GROWTH AND OVERLAPPING GENERATIONS MODELS IN ECONOMIC CONVERGENCE AND INEQUALITY: A REVIEW

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ABSTRACT

This study explains the dynamics in the Optimal Growth [OGR] and Overlapping Generations [OGE] models and their implications for (real) GDP per capita [RGDPPC] in different countries, short-run and long-run. This analysis uses RGDPPCs for ten countries consisting of five per each developed and developing category for 116 years. Sri Lanka is used as the favourite destination and calculated the RGDPPC ratios. Data on RGDPPC for ten countries explains that the relative differences between RGDPPC ratios and the baseline are varying over time. Also, it demonstrates a high variation in the short-run dynamics between countries. Both models predict a convergence of economies into a steady-state having the same amount of RGDPPCs in the long run. This prediction appears to be acceptable in the analysis. Having Sri Lanka as the benchmark, Japan exhibits low RGDPPC values at the initial stage and eventually gets closer to the RGDPPCs of developed countries. This is not a direct convergence to the steady-state but convergence to the RGDPPC level of developed countries. Also, the concept of efficient contributions by generations in the OGE model was considered and it reflects a more realistic reasoning as per the short-run dynamics, but that resulted in making differences across countries per capita GDP in the long run. The long-run dynamics revealed that growing inequality is a common issue in developing nations as a very low percentage of populations enjoys a high proportion of national output.

JEL Classification: E27, E19, O47, O57

KEYWORDS: Convergence; Optimal growth; Overlapping generations; Real per-capita GDP

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1. INTRODUCTION

New classical macroeconomics led economists to identify the importance of applying streamlined microeconomic models to study the aggregate economy. Thus, two landmark models in the modern macroeconomics are the Optimal Growth [OGR] and Overlapping Generations [OGE] models. These models have microeconomic foundations and are general equilibrium models (Bewley, 2007). Both models describe the behaviour of agents and focus on the fundamentals such as utility functions and initial endowments for consumers and production functions for firms. Also, agent's problems are stated, and equilibria are reviewed for utility maximization, profit maximization, and market clearance (Koopmans, 1963; John & Pecchenino, 1994; Bewley, 2007; Tvede, 2010; Kim & Spear, 2020; Gali, 2021).

Kim & Spear (2020) studied the 'Markov equilibrium' in various stochastic OGE models. Thus, it was an application of applied game theory together with dynamic strategic interactions towards macroeconomic equilibria. Gali (2021) analyzed an extension of the New Keynesian model while including the features of OGE model. Such, methodological studies emphasize the interest as well as the applicability of New Classical growth models in academia. This has been a trademark in modern economics as both OGR and OGE models let academics to think beyond Keynesian thoughts.

Both OGR and OGE models are indefinitely important in examine the optimal growth targets, strategies, and their potentials. The literature highlights various attempts that tested the applicability of these models in different economies (John & Pecchenino, 1994; Cazes et al., 1994; Mino & Shibata, 1995; Hviding & Merette, 1998; Demange & Laroque, 2000; Melkonyan & Grigorian, 2008; Watanabe, 2008; Weil, 2008; Garriga, 2017; Das et al., 2018; Khan & Lidforsky, 2019; Sun et al., 2020).

For instance, Sun et al. (2020) tested the connection between environmental performance assessments and global economic growth following the insights from efficiency and growth convergence as per OGR and OGE models and their growth targets.

Consequently, the foremost objective of the study is to examine the dynamics in the two models and their implications for Real GDP Per Capita (RGDPPC) across the developed and developing countries both in the short run and in the long run. Initially, the study elaborates technical differences between OGR and OGE models followed by an empirical analysis using RGDPPCs for ten countries consisting of five per each developed and developing categories for 116 years using data from the Maddison Project (Bolt et al., 2018).

In the analysis, Sri Lanka is considered as the favourite destination and figures are used with time on the first axis and the ratios of GDP per capita of the non-favourite countries and GDP per capita of Sri Lanka on the second axis. Thereafter, the study discusses the dynamics of two models and reflections on the short-run, long-run differences following the analysis.

2. OGR AND OGE MODELS

The OGR and OGE models are two pillars in new classical macroeconomics. They are dynamic models with time extending to infinity, but in OGR economies consumers live forever and in OGE economies consumers live for finitely many years (Koopmans, 1963; John & Pecchenino, 1994; Bewley, 2007; Tvede, 2010). The dynamics of the OGR model are described by a comparison of combinations of household consumption and capital over time with respect to the household's optimization problem. Higher the consumption [c_t] in the next year indicates a higher income level next year.

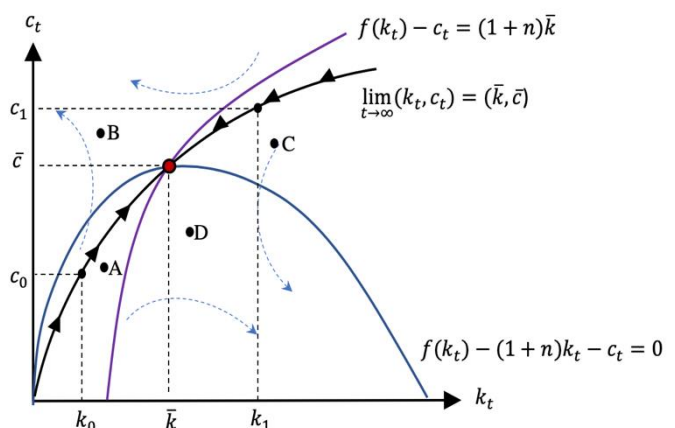


Figure 1. Steady State - OGR Model

Figure 1 reflects all the dynamics of the OGR model. Any economy with c_t, k_t combination within the area “A” experiences a situation with high growth in both capital and consumption in the short run, and it increases its per capita GDP and eventually moves to the \bar{k}, \bar{c} combination in the long run. Any country with c_t, k_t combination within the area “C” eventually moves back to the \bar{k}, \bar{c} in the long run. The area “B” represents higher levels of consumption but with low capital, and it reflects the problem with feasibility. Also, area “D” represents higher levels of capital with low consumption, and it reflects the problem with transversality.

Ultimately, this model predicts that all economies eventually reach the steady-state (\bar{k}, \bar{c}) and be equally rich in the long run regardless of the initial conditions of its capital strengths.

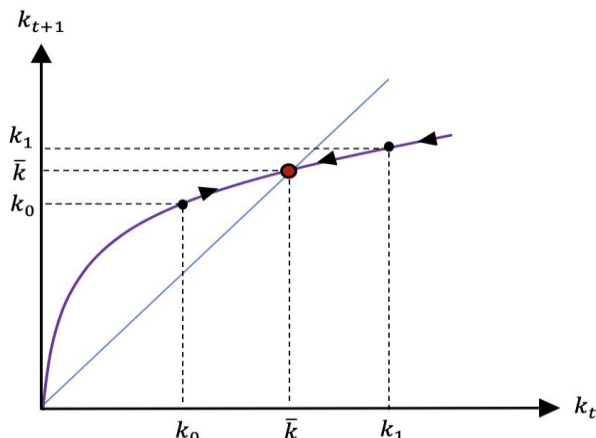


Figure 2. Steady State - OGE Model

The OGE model requires each generation to actively participate in economic activities as the equilibrium changes over time with new generations. Here we consider the combinations of per capita capital (k_t and k_{t+1}) across generations.

Figure 2 demonstrates how the steady-state is globally stable according to the OGE model. Here the equilibria are determinate and path independent. The equilibria are determinate as there is a unique sequence of capital for all initial endowment of savings. Also, it is path independent as the initial conditions of the economy do not matter for the long-run convergence. Thus, a country with k_0 level of capital has its own unique combination across generations and reaches higher RGDPCC in the short-

run till it reaches the steady-state with a constant \bar{k} .

On the other hand, a country with less contribution from the next generation reaches back to the steady state by lowering its RGDPCC in the short run. Also, OGE economies can end up in multiple equilibria solutions but it is not emphasized in this study. Eventually, the OGE model also implies that the countries have dynamics in the short run but converge into a steady-state \bar{k} irrespective of the initial condition of the country. Thus, both models predict a convergence of economies into a steady-state having same amount of RGDPCCs in the long-run but have clear differences in the way they describe the scenario.

3. COMPARISON OF RGDPCC RATIOS

This analysis uses RGDPCCs for ten countries consisting of five per each developed and developing categories for 116 years. Sri Lanka is used as the favourite destination and calculated RGDPCC ratios.

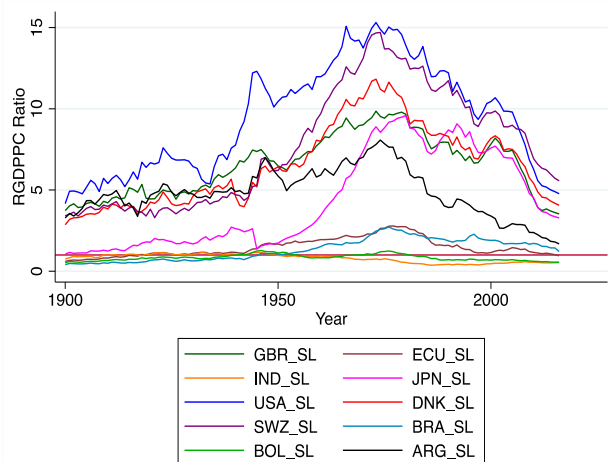


Figure 3. RGDPCC Ratios of all Countries

Figure 3 illustrates the RGDPCC Ratio of 10 Countries over time. The red horizontal line indicates the RGDPCC ratio ‘1’ as the baseline for the comparison. The ratio is 1 when the RGDPCC of Sri Lanka equals to the RGDPCC of other economies. We can observe that there is an increase of RGDPCC in majority of economies on average till the 1970s-1980s compared to the baseline. Thereafter, the countries demonstrate a declining trend in the ratio. In addition to that, the highest RGDPCC ratio of 15.315 is recorded by the United States and the

lowest of 0.373 by India in 1986. Also, this figure shows us that two clusters of countries depend on the differences between the ratios of developed and developing countries. The ratios for the developed countries are demonstrated in figure 4. The developed countries are more likely to represent a separate cluster. The RGDPCC of the Japanese Economy was comparatively lower at initial stages of the comparison, but it has ended up in a similar track after the 1970s up to 2016. Thus, the developed economies are 3-6 times higher than the Sri Lankan RGDPCC by 2016

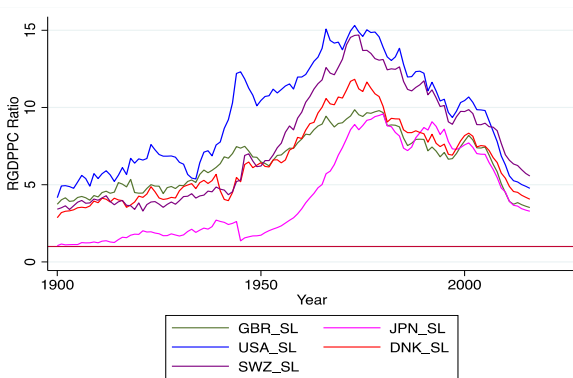


Figure 4. RGDPCC Ratio of Developed Countries

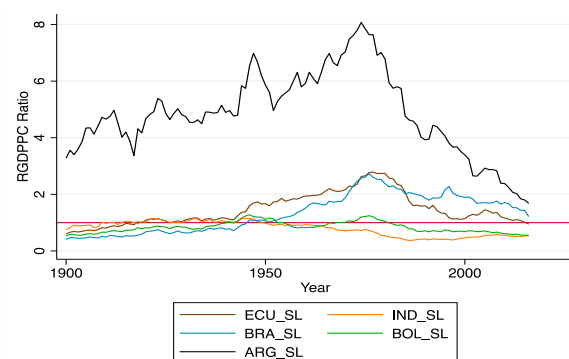


Figure 5. RGDPCC Ratio of Developing Countries

Then figure 5 represents the second cluster that consists of developing countries, Ecuador, Brazil, Argentina, India and Bolivia. The figure demonstrates a clear difference between the dynamics of RGDPCC of Argentina from other developing countries. However, eventually, the developing countries are 0.3-1.8 times higher than the baseline by 2016. Also, we can observe that the Japanese RGDPCC was similar to the baseline in the

1900s, and it has ended up in the cluster for developed economies over time. In contrast, Argentina had high RGDPCC at initial times but has ended up in the cluster for developing economies.

4. SHORT-RUN DYNAMICS

According to both OGR and OGE models, the short-run dynamics lead an economy towards a steady state in the long-run. When we compare the data on RGDPCC for ten countries, we can see that the relative differences between RGDPCC ratios and the baseline are varying over time. Also, it demonstrates a high variation between the short-run dynamics between countries. We know from the OGR model that the income level of an individual depends on the consumption, and it encourages buying more capital. This is indicated by the economies such as the USA, Switzerland, and Japan by short-run boosts in their RGDPCC values in different time periods and what should lie in the area “A” of figure 1. However, the steady-state in this example is the baseline where all economies should converge in the long run but not feasible in the short-run dynamics for these countries. Also, the OGR model is not clear with India and Bolivia. Since India and Bolivia are very similar to the baseline ratio until the 1950s and then indicates a different behaviour with a decline of their RGDPCCs. This model does not have a specific explanation for such dynamic behaviours across countries.

Then we can consider the short-run dynamics of the OGE model. It seems that the OGE model has a fairly realistic explanation for such data sets because it focuses on the importance of effective combinations of k_t across generations. Each combination has its uniqueness as countries may have different RGDPCC values. For instance, India experiences a declining trend in their RGDPCC as the contribution of their new generations are ineffective or low in the short run.

Moreover, in OGR economies, the consumer does not put enough weight into the future. However, the data on different countries show how they reach different income levels across generations. According to the OGE model, the concept of efficient contributions by

generations was concerned and it reflects more realistic reasoning. We know that both models predict a convergence of economies into a steady-state in the long run and no matter what the initial conditions are. This prediction appears to be acceptable to some extent according to the data. For instance, Japan exhibits low RGDPPC values at the initial stage and eventually it get closer to the RGDPPCs of developed countries. This is not a direct convergence to the steady-state but a convergence to the RGDPPC level of developed countries. Also, we can see how the rapid adjustments in Argentina reach the RGDPPC range of developing countries. Also, figure 3 encourages us to expect convergence to the baseline usage in the distant future as there is a severe trend shown in data though it was not there in 2016.

5. LONG-RUN DIFFERENCES

The creation of the economic output is more complex than most of the economic models describe. As a result, we can observe a long-run difference in RGDPPCs. If we consider the Japanese economy as an example, they had the worst experience during the World War II and later reflects significant improvements in their RGDPPC. The Indian economy suffers from a growing population and inequality as their RGDPPC decreases over time. Therefore, inequality, unemployment, corruptions, high birth and mortality rates, policy changes, and technology are some reasons for such long-run differences. When we try to identify these reflections in relation to the two models, OGR model exhibits some unrealistic features as it does not focus some structural contexts in the countries. According to the model, a consumer lives forever, and demographic structure seems unrealistic. The issues in mortality, ageing population and population growth are not considered, and even the issue of unemployment is not considered due to this limitation of the model. Anyway, the OGE model appears to be more realistic as it considers that consumers live for finitely many days.

Growing inequality is a common issue in developing nations as a very low percentage of populations enjoys a high proportion of national output. Therefore, this generates instability in the explanation given by OGE model regarding the

effective contribution of individuals from all generations for production. For instance, Indian economy struggles from both high population growth and inequality which creates issues such as less contribution from the economically active population and high unemployment. Also, both models do not focus on factors such as technology and market structures apart from the spot market, which can create major differences. Especially, the advanced technology can architect differences in income levels over time. Therefore, such issues can create significant differences to make long-run differences in RGDPPCs against the predictions by the models on long-run convergence to the steady-state.

6. CONCLUSION





New classical macroeconomics led economists to identify the importance of applying streamlined microeconomic models to study the aggregate economy. Two landmark models in the modern macroeconomics are the OGR and OGE models. Both models predict a convergence of economies into a steady-state having the same amount of RGDPPCs in the long-run but with clear differences in the approaches. The analysis on RGDPPC for ten countries reflect relative differences between RGDPPC ratios and the baseline and are varying over time. It exhibits high variation between the short-run dynamics between countries. Further, we observe long-run difference in RGDPPCs. Inequality, unemployment, corruptions, high birth, mortality rates, policy changes, and technology are some fundamental reasons for such long-run differences. Consequently, the OGR model exhibits unrealistic features as it does not focus on some of the key structural contexts highlighted above. A consumer lives forever, and the demographic structure seems unrealistic in the OGR. In contrast, the OGE model appears to be more realistic as it considers that consumers live for finitely many days. Moreover, in optimal growth economies, the consumer does not put enough weight into the future. However, the data on different countries show how they reach different output levels depending on their plans into future and the degree of weight creates differences across the per-capita GDP between countries. According to the OGE model, the concept of efficient contributions by

generations such as baby boomers, X, Y, Z and Alpha was concerned, and it reflects more realistic reasoning. Yet, in contrast to the predictions made by OGE model, data show differences in per-capita GDPs between developed and developing countries in the long-run due to prolonged structural differences.

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GEOSPATIAL MAPPING OF GROUNDWATER POTENTIALITY IN SOORIYAWEWA DIVISIONAL SECRETARIAT DIVISION BY UTILIZING GIS


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ABSTRACT

The dry zone of Sri Lanka is affected by drought conditions owing to a lack of rainfall. Hence, mapping the distribution of groundwater potential zones is vital for water management. The Hambantota district, which is in the dry zone is a severely afflicted area due to lack of rainfall, and Sooriyawewa divisional secretariat area faces water scarcity. Therefore, this study aims to map groundwater potentiality in the Sooriyawewa divisional secretariat division using a geographical information system. For this study, spatial interpolation techniques, weighted overlay analysis, georeferencing, and digitizing methods were used. In this study, the annual average rainfall, geology, geomorphology, drainage density, lineament density, land use land cover, slope, and soil maps were prepared, and integrating those maps, the final groundwater potential zones map was prepared by using ArcMap 10.5 software. The study found that there were no high-potential groundwater zones in the Sooriyawewa divisional secretariat division and it already consists of low and moderate ranges. Therefore, the final groundwater potential zone map was categorized as very low, low, and moderate. The Percentages of area Coverage according to classes as, very low 2%, low 91%, and moderate 7%. This study can be highly helpful in identifying the groundwater potential zones in the Sooriyawewa divisional secretariat division and in preventing water scarcity because identified groundwater potential zones can be used for effective water management and provide essential information to responsible authorities for decision-making. Furthermore, the identified potential zones can be used for rainwater harvesting and can be used properly for future consumption.

KEYWORDS: Georeferencing, Geographical Information System, Spatial Interpolation, Weighted Overlay, Groundwater Potential

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1. INTRODUCTION

"Water in a zone of saturation, fills the open pores of mineral grains or fissures and cracked rocks in a rock mass," is one of the definitions of groundwater. Groundwater is a crucial natural resource in the consistent and expensive supply of drinking water in both rural and urban regions. The quantity of groundwater accessible in each location is referred to as groundwater potential, and it is determined by a few hydrologic and hydrogeological parameters. A dimensionless quantity that serves in the prediction of available groundwater regions in a given area is subsurface potential (Pathmanandakumar, Thasarathan and Ranagalage, 2021).

The slope, weathering depth, the presence of cracks, canals, surface water bodies, and irrigated fields all influence groundwater conditions. Geological, geomorphological, and hydrological data are the most common types of data accessible for groundwater research (Ganapuram et al., 2009). For years, governments and research organizations all across the world have attempted to analyze groundwater potential and anticipate its spatial distribution (Oh et al., 2011).

The value of groundwater is increasing globally as an effect of a variety of causes including population expansion, enhanced irrigation practices, industrial uses, etc. Groundwater consumption and demand have grown as a result of population expansion, grown irrigated agriculture techniques, and economic development, with little regard for the significance of groundwater's environmental balance. In Sri Lanka, groundwater is often used for drinking as well as other household needs. The potential for groundwater in Sri Lanka is less than the nation's surface water. Therefore, Groundwater potential is projected to be 7.8 billion Cubic meters per year. In Sri Lanka's dry zone, the primary source of water for rural inhabitants is groundwater. One of the greatest choices for helping dry-zone residents improve their lives by improving agricultural production without depleting groundwater supplies is to develop sustainable groundwater resources. Sri Lanka's annual freshwater withdrawals were projected to be 13 billion cubic meters by the

World Bank in 2014. In the dry zone of the country, water scarcity is the most pressing concern. The Hambanthota district's need for freshwater is increased during the dry season due to a lack of surface water resources (Pathmanandakumar, Thasarathan and Ranagalage, 2021).

Due to the unequal distribution of annual rainfall, the dry regions of Sri Lanka cope with drought regularly. With the district's ongoing major construction developments, water consumption will rise in the next few years (Senanayake et al., 2013). Hence, for effective water management, it is essential to identify the distribution of groundwater potential zones. Sooriyawewa Divisional Secretariat Division (DSD) consists of many natural resources but most of the people living in that area are not economically sound. Drinkable water, as well as all other water resources, are critical in this region for many reasons, involving household activities, farming uses, and ongoing initiatives. Due to the lack of a well-defined water management system in the Sooriyawewa DSD, there is a probability of future water scarcity. People in this region of Sooriyawewa DSD are also in despair as a result of this issue. Due to the low-income level of most people, they cannot afford the water from the National Water Supply and Drainage Board (NWSDB). But if there is a correct solution for this issue much money can be saved to be used for other purposes. Hence, it is necessary to prepare groundwater potential zone maps to provide essential data to responsible authorities. As a result, the study's most important purpose is to detect the groundwater potential zones in the Sooriyawewa DSD.

2. METHODOLOGY

Study Area

Sooriyawewa Divisional Secretariat is a Divisional Secretariat located in the Hambantota District, of Southern Province, Sri Lanka (Figure 1). Sooriyawewa DSD consists of 21 Grama Niladhari Divisions (GND). It has an extent of 185.6312 km². It has a population of 43680 people and occupied an area of 192 square kilometres in 2006 (Department of Census and Statistics – Sri Lanka). Topographically the landscape varies from category Argo ecologically and the division belongs to the agroecological zone.

27.6° C is the average temperature. The warmest month is July, and the coolest month is January. 1137.1 mm is the average annual rainfall. (Hambantota Center).

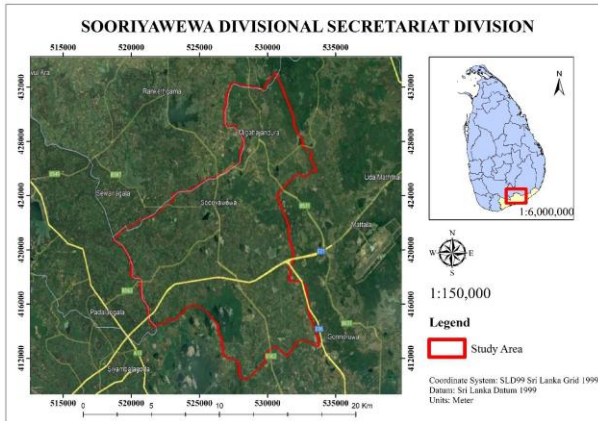


Figure 1: Study area under investigation, Sooriyawewa DSD Sri Lanka

Data used

In this investigation was used secondary data for the analysis. Rainfall data, Land Use Land Cover (LULC) data, soil map, contour data, geology and geomorphology map of Sri Lanka, and stream network data were used for the analysis. And also well coordinates and water depths of the wells in the Sooriyawewa DSD were used for the validation.

15-year period rainfall data were obtained from the Meteorology Department from 2005 to 2019. LULC data, contour data, and stream network data were obtained from the Survey Department of Sri Lanka. Data of wells were obtained from NWSDB for validation.

Data analysis

The analysis aims to discover potential groundwater zones. The type of this study was quantitative and the design of this research was descriptive. ArcMap 10.5 software was used for the data analysis. For this study, eight parameters were considered, i.e. LULC, soil, slope, rainfall data, lineament density, drainage density, geology, and geomorphology. Rainfall data were one of the main focuses of this analysis. Using the kriging interpolation technique, the rainfall distribution of Sri Lanka from 2005-2019 was

obtained (Sandamali et al., 2021). Therefore kriging interpolation technique was used for this study to obtain the rainfall distribution of the Sooriyawewa DSD. Using the above past 15 years of rainfall data average annual rainfall map of the Sooriyawewa DSD was prepared.

By using LULC data obtained from the Survey Department LULC map was prepared. To prepare the soil map of the Sooriyawewa DSD, World soil maps were downloaded by using the Food and Agriculture Organization of the United Nations website and separated the soil layer of the Sooriyawewa DSD. By using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) contour data Digital Elevation Model (DEM) was prepared and a slope map was obtained utilizing that DEM data set of the Sooriyawewa DSD. Using an image of a map of geomorphology and geology map of Sri Lanka, geomorphology and geology maps of the Sooriyawewa DSD were generated through georeferencing and digitizing.

A lineament Density map was generated by utilizing ASTER DEM. Before preparing the lineament density map obtained the hillshade and lineament polylines were digitized. A drainage density map was generated by utilizing stream network data. By using weighted overlay analysis all those maps were integrated and the final map of the groundwater potential map of the Sooriyawewa DSD was generated. The ranks and weights were assigned by modifying previous literature (Modified after Senanayake et al., 2016; Pathmanandakumar, Thasarathan and Ranagalage, 2021). Table 1 and 2 shows the rank assigned to the parameter influencing and Weights assigned to classes of each theme based on their influence on groundwater potentiality.

Finally, utilizing coordinates of wells and water depths validation was done. Before doing the validation, first, the most suitable interpolation method was identified for the groundwater data mapping. Therefore, Root Mean Square Error (RMSE) calculations were done for Inverse Distance Weighted (IDW), Ordinary kriging, and Spline interpolation techniques.

Table 1: Ranks assigned to the parameters influencing groundwater potentiality (Modified after Senanayake et al., 2016 and Pathmanandakumar, Thasarathan and Ranagalage, 2021)

Parameter	Rank Assigned
Rainfall	15
Land Use Land Cover	10
Slope	11
Soil	14
Geology	15
Geomorphology	12
Lineament Density	13
Drainage Density	10

Table 2: Weights assigned to classes of each theme based on their influence on groundwater potentiality (Modified after Senanayake et al., 2016 and Pathmanandakumar, Thasarathan and Ranagalage, 2021)

Themes and Classes	Weight Assigned
Rainfall	
1497-1500	2
1501-1550	3
1551-1650	4
1601-1650	6
1651-1700	9
Land use Land cover	
Built up Area	1
Barren land	2
coconut	6
Open Forest	3
Forest plantation	3
Marsh	7
Other Cultivation	4
Paddy	7
Playground	1
Rock	2
Scrub Land	5
Sparsely Used Cropland	4
Home Graden	2

Water Bodies	8
Soil	
Alluvial soils of variable texture and drainage; flat terrain	4
Erosional remnants of steep rock land and various lithosols	1
Redish brown earth and low humic gley soils	6
Slope	
0-1	9
2-3	8
4-5	6
6-7	4
8-12	3
13-32	1
Drainage Density	
0-1	1
2-3	2
4-5	3
6-7	5
8-10	6
11-16	8
Lineament Density	
0-0.5	1
0.5-1	4
1-1.5	6
Geomorphology	
Wet zone Chrnockitic	7
River Differentiated	7
Lower Intermediate plantation Chrnockitic	3
Dry zone Chrnockitic	4
Geology	
River	7
Rock	3
Chrnockitic biotite geniss	2

3. RESULTS AND DISCUSSION

The potential of groundwater in the Sooriyawewa DSD was examined in this study. LULC map, soil map, rainfall map, lineament density map, drainage density map, slope map, geology and geomorphology maps were prepared. All the maps were prepared in SLD 99 Sri Lanka grid 1999.

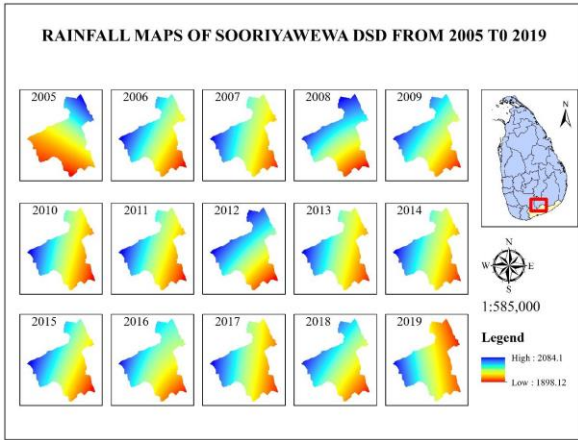


Figure 2: Rainfall Maps of 15 years in Sri Lanka

The 15 years of rainfall data (2005-2019) were considered for the prepared average annual rainfall map (Figure 2). Using the above past 15 years of rainfall data, the average annual rainfall map of the Sooriyawewa DSD was prepared. The average annual rainfall ranges between 1497-1700 mm and it was classified as five classes given the weights of each class (Figure 3).

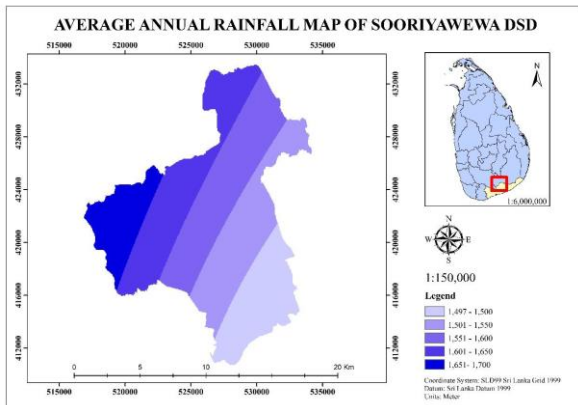


Figure 3: Average Annual Rainfall Map of Sooriyawewa DSD, Sri Lanka

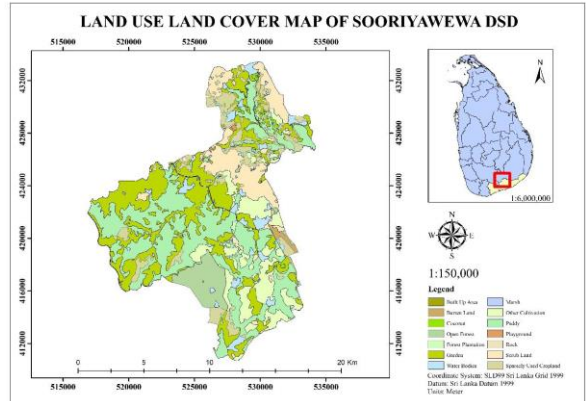


Figure 4: Land Use Land Cover Map of Sooriyawewa DSD, Sri Lanka

The LULC map of the Sooriyawewa DSD, Sri Lanka was classified as built-up area, barren land, coconut, open forest, a forest plantation, marsh, other cultivation, paddy, playground, rock, scrubland, sparsely used cropland, home garden, and water bodies for giving the weights to each class (Figure 4).

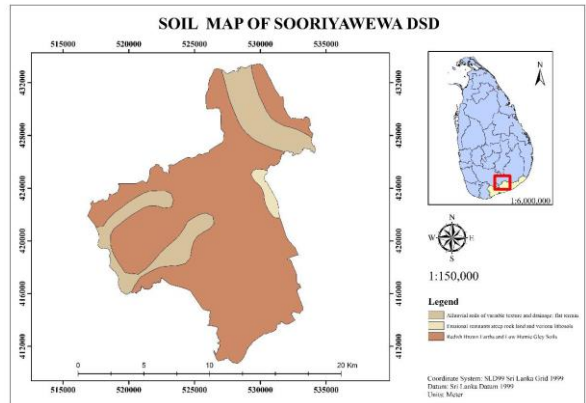


Figure 5: Soil Map of Sooriyawewa DSD, Sri Lanka

The Soil Map of the Sooriyawewa DSD, Sri Lanka was generated according to the soil type and classified into three classes, i.e. Alluvial soils of variable texture and drainage, Erosional remnants of steep rock land and various lithosols, and Reddish brown earth and low humic gley soils (Figure 5).

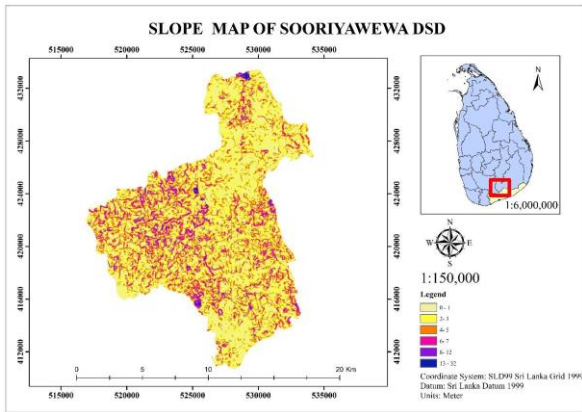


Figure 6: Slope Map of Sooriyawewa DSD, Sri Lanka

The range of the slope in the Sooriyawewa DSD between 0-32 and it was classified into six classes according to natural breaks (Figure 6).

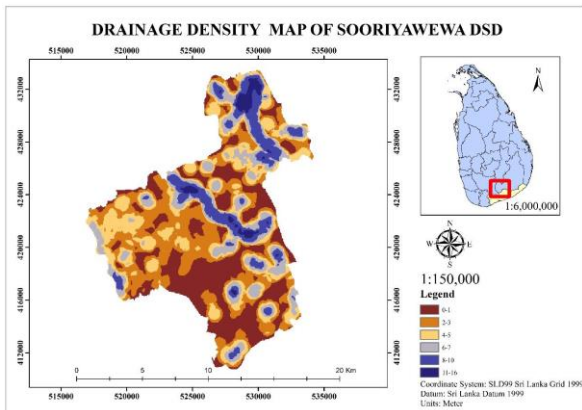


Figure 7: Drainage Density Map of Sooriyawewa DSD, Sri Lanka

The range of the drainage density in the Sooriyawewa DSD was between 0-16, and it was classified into six classes according to natural breaks (Figure 7).

By using ASTER DEM, lineament density map was prepared. The range of the lineament density in the Sooriyawewa DSD was between 0-1.5, and it was classified into three classes (Figure 8).

The Geomorphology map was generated according to the type and was classified into four classes, i.e. Wet zone Chnrockitic, River Differentiated, Lower Intermediate plantation Chnrockitic, and Dry zone Chnrockitic (Figure 9).

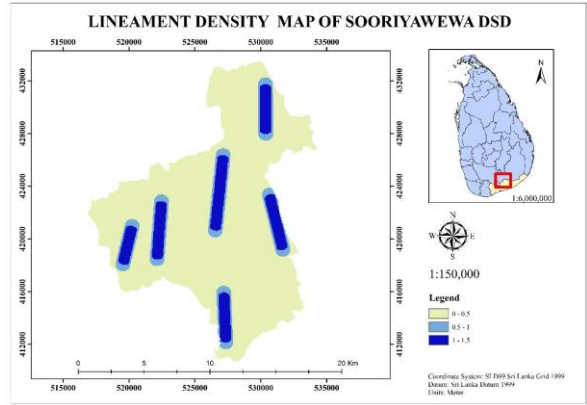


Figure 8: Lineament Density Map of Sooriyawewa DSD, Sri Lanka

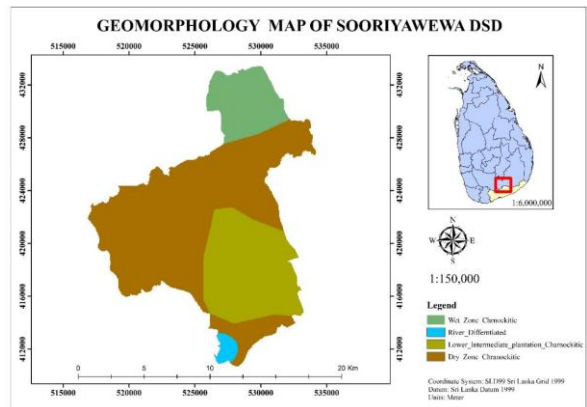


Figure 9: Geomorphology Map of Sooriyawewa DSD, Sri Lanka. Source: Open access data from the European Soil Data Centre (ESDAC)

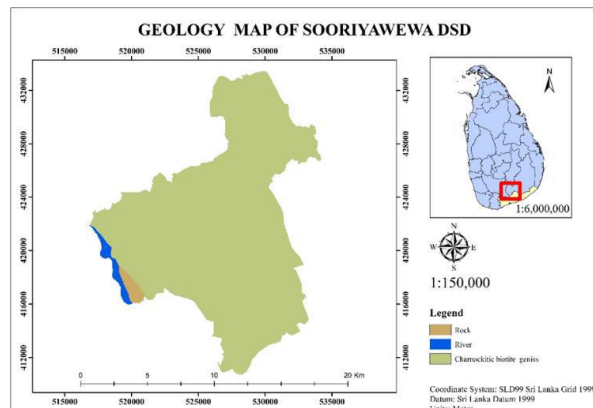


Figure 10: Geology Map of Sooriyawewa DSD, Sri Lanka. Source: Open access data from the European Soil Data Centre (ESDAC)

The Geology map was generated according to the types and was classified into three classes, i.e. Charnockitic biotite gneiss, Rock, and River (Figure 10).

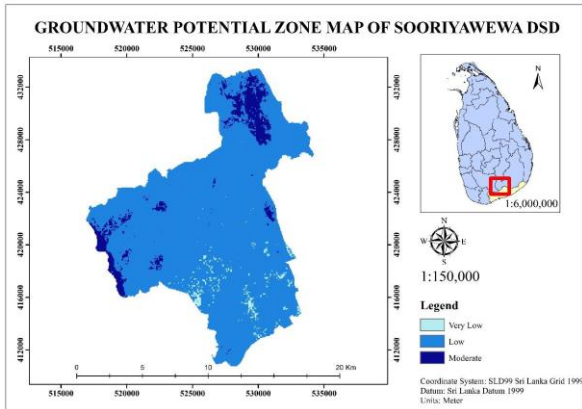


Figure 11: Groundwater Potential Zone Map of Sooriyawewa DSD

According to the result, the Sooriyawewa DSD does not consist of high potentiality, and it already consists of low and moderate ranges. Therefore, the final map was classified into 3 classes such as very low, low, and moderate (Figure 11). According to the results, the 34075km² area coverage is very low class, 174.73km² area is low class, and 14.1875km² area is moderate class. As a percentage very low - 2%, low - 91%, and moderate - 7%.

Table 3: Percentages of area Coverage according to classes

Groundwater level	Area (km ²)	Percentage
Very Low	3.4075	2%
Low	174.73	91%
Moderate	14.1875	7%

By using well data, validation was done. For the validation, RMSE calculations were done to find the suitable interpolation technique. The result of the RMSE calculations indicates the minimum error in the spline interpolation technique. The spline interpolation technique was the most suitable method for mapping the groundwater data according to RMSE calculation.

Therefore, spline interpolation was used for the validation of the study.

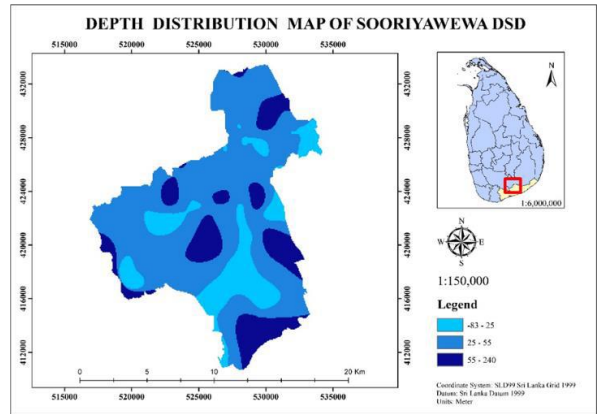


Figure 12: Depth Distribution Map of Sooriyawewa DSD

The interpolated map of groundwater data, classified according to the depths of groundwater. In Sooriyawewa DSD depths of groundwater succeed in the -83 to 240 range (Figure 12). Therefore, it was classified into 3 classes according to (Siddi Raju, Sudarsana Raju and Rajasekhar, 2019). In this study, the -83-25 range was considered very low, the 25-55 range was considered low, and the 55-240 range was considered moderate. For the validation, 30 points were collected from the final groundwater potential zone map varied with very low, low, and moderate as shown in Figure 11. Those points were extracted with real data obtained from the NWSDB. The overall accuracy of the result was 82% according to the RMSE calculation.

This study can also be applied to other areas in Sri Lanka that suffer from groundwater scarcity. Mapping the distribution of potential zones of groundwater is vital for water management to launch public water distribution projects more effectively. This analysis can provide essential information to responsible authorities for decision-making. Cost controlling through proper analysis of projects like minimum water line to feed maximum clients, wastage due to improper plantation in unsuitable areas like those without sufficient groundwater storage and established tube wells in places with less water level, etc. Moreover, with the help of the NWSDB and the survey department of Sri Lanka the annual

groundwater potential zone maps can be produced and updated for certain areas that are mainly faced with droughts. Focusing on the above-mentioned, future development can give huge job opportunities to the people in this area by introducing new commercial crops and establishing new croplands.

As a recommendation, this analysis can be used to prevent water scarcity and to identify the groundwater potential zones. Hence, this analysis can be used for decision-making about groundwater potentiality. Groundwater can be used for day-to-day work and the potential zones should be used effectively. This study can direct farmers to effective crop cultivation by analyzing the crops and their productivity with the water level, and hybrid crops that match the water level and the client's requirements can also be introduced for the zone.

4. CONCLUSION

In the world, there are many natural resources. Among them, groundwater is one of the most important and valuable water resources. For residential, agricultural, and industrial uses, groundwater resources are significant natural resources. Due to the rising population, more sophisticated irrigation techniques, and industrial use, groundwater demands have significantly increased.

Sri Lanka's dry zone frequently experiences serious drought conditions, and the situation gets worse over time. The Hambantota district, which is in the dry zone, appears to be a severely afflicted area based on groundwater availability. To solve this issue, it is essential to have an effective water management system, to preserve the current surface and groundwater resources, and to recycle the groundwater and surface water waste.

The area under this analysis is the Sooriyawewa DSD because it is located in the Hambantota district and is facing the same issues. Many natural resources can be found in Sooriyawewa DSD, but most of the people there are not well off economically. Drinkable water, as well as all other water resources are critical in this region for a variety of reasons, including household activities, agricultural uses, and ongoing initiatives. As a result, Sooriyawewa DSD is suffering from the same

problems. Due to the polluted water, people are also facing several health issues such as the unidentified kidney disease, urinal infections, and considerable effects on their oral health (depositing of calcium on the tooth surface). The presence of heavy metal ions and salts in groundwater can be stated as the main reason for the above health issues. The outcome of this study identifies the groundwater potential zones in Sooriyawewa DSD. The Sooriyawewa DSD's groundwater potential mapping can have a tremendous impact on both the island and the related area.

The scarcity of drinkable groundwater across the most parts of Sri Lanka will cause heavy trouble in the future and groundwater is a vital resource sustaining the home supply of water, irrigated agriculture, and industries. Matters about the potential degradation of the resources, deteriorating water quality, and other risks have been raised due to the massive use of groundwater in the past few decades. Given the public's misunderstanding that groundwater is a limitless water supply and limits in hydrogeologic characterization and understanding of its reaction, groundwater systems are used inefficiently and even wastefully. Consequently, the provision of drinking water is greatly influenced by groundwater supplies.

In this analysis, the main objective was to map the groundwater potential zones in the Sooriyawewa DSD by utilizing GIS and the ability was critical for successful analysis, prediction, and validation. LULC maps, soil maps, rainfall maps, lineament density maps, drainage density maps, slope maps, drainage density, geology, and geomorphology maps were prepared by using ArcGIS and thematic maps were generated. Thematic maps were overlaid and the potential zones of groundwater were obtained. Finally, distribution levels of groundwater potential zones and mapped groundwater potential zones in the Sooriyawewa DSD were identified.

This analysis is highly helpful in preventing water scarcity by identifying the groundwater potential zones in the Sooriyawewa DSD and directing public water distribution projects like tube wells. Furthermore, this investigation can be used for decision-making about groundwater potentiality in Sooriyawewa DSD and further analysis. In

Sooriyawewa DSD identified groundwater potential zones as very low, low, and moderate. According to the results, the 34075Km² area coverage is very low class, 174.73Km² area is low class, and 14.1875Km² is moderate. As a percentage very low -2%, low -91%, and moderate -7%. Although there are no high-potential zones, there is a significant amount of medium potential. Therefore, groundwater can be used for the day-to-day work and the potential zones should be used effectively. And also, if properly used the identified potential zones can be used for scarcity prevention in the Sooriyawewa DSD. As there is minimal rainfall in Sooriyawewa DSD, the identified potential zones can be used for rainwater harvesting, which can be used properly for future consumption.

5. ACKNOWLEDGEMENT

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TRANSLATION AND CROSS-CULTURAL ADAPTATION OF TRAIT EMOTIONAL INTELLIGENCE SCALE-SHORT FORM (TEIQue-SF) INTO SINHALA

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ABSTRACT

Despite emotional intelligence (EI) being recognized as important in all areas of a person's life, measuring the emotional aspects of most Sri Lankans remains challenging due to the lack of suitable psychometric assessments. The current study translated and carried out the cross-cultural adaptation of the Trait Emotional Intelligence Scale-Short Form into Sinhala. Trait Emotional Intelligence Scale-Short Form has been recognized as a valid and reliable instrument to measure emotional intelligence. The tool was translated by a bilingual, licensed clinical psychologist, incorporating the World Health Organization guidelines for translating and adapting instruments. The translation was evaluated and modified by an expert panel. The second panel rated the translation for content validity. The comprehension test was done with 15 participants who belonged to different educational backgrounds. The back translation was carried out by a professional translator. The adaptation was completed in consultation with the original author of the scale. The majority of the items received a Content Validity Index score of one (01). The comprehension test results indicated that the translated Trait Emotional Intelligence Scale-Short Form was easily understood by Sinhala speakers with an average education. Trait Emotional Intelligence Scale-Short form can be validated for Sinhala speakers of Sri Lanka by future researchers.

KEYWORDS: *EI, trait emotional intelligence, Sri Lanka, adaptation, Sinhala*

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1. INTRODUCTION

1.1 Emotional Intelligence

In the recent past, emotional intelligence (EI) has been recognized for its impact on human survival. EI can predict success in many areas of a person's life, including career, relationships, education, etc., as it significantly impacts mental, social, and physical wellbeing (Urquijo et al., 2019; Jardine et al., 2022; Rehman et al., 2022; Extremera & Fernández-Berrocal, 2006). Thus, tools for measuring EI have been increasingly incorporated to investigate individuals' well-being in clinical settings. Although EI is essentially defined as the ability to recognize and regulate emotions, within the current models of EI, this broad definition is further divided into different competencies. Emotional perception, emotional understanding, and emotional regulation are commonly described as EI-related competences. Emotional perception refers to the ability to recognize and analyze emotional cues that indicate one's own and others' emotions. Emotional understanding refers to the ability to analyze emotions in a more retrospective manner. Likewise, emotional regulation refers to analyzing and rethinking emotional responses (Rubio et al., 2022). Better emotional intelligence is seen as a factor that improves general health and better adaptation to challenging situations (Andrei et al., 2022).

1.2 Trait Emotional Intelligence

Current scientific literature refers to more stable patterns of skills related to emotional intelligence as trait emotional intelligence (Trait EI). Trait EI is recognized as a personality trait with predictable long-term outcomes for the individual. The construct of trait EI is seen as the summation of the affective aspects of an individual. Some researchers define it as a stable set of "emotion-related self-perceptions and adaptive emotional dispositions" (O'Connor et al., 2017). Trait EI has a strong positive correlation with mental health and wellbeing. Further, high trait EI results in better adaptation to stress. When there is excessive stress, high trait EI is believed to act as a protective factor. Studies have shown its protective ability during the

COVID-19 pandemic as well (Andrei et al., 2022). Further, trait EI demonstrates a correlation with quality of life in patients with chronic illnesses. Specifically, research has demonstrated that receiving training in traits related to EI could improve the quality of life in patients with breast cancer (Chen et al., 2021). Trait EI has also been implied as an important variable that predicts substance abuse and addiction in young populations (Yubero et al., 2021). In addition, trait EI has also shown a substantial impact on happiness levels (Badri et al., 2021). Considering the impact of EI on human existence, having appropriate tools to measure this important construct will be highly useful.

1.3 Barriers to Measuring Emotional Intelligence in Sri Lanka

Sri Lankan culture differs from western cultures in terms of expressing emotions. Nevertheless, clinical experience shows that emotional aspects of individuals have the same effect on people as more western perspectives have recognized. Interestingly, when people attend psychotherapy and counseling, doctors spend a lot of time trying to understand their feelings and emotions due to the lack of emphasis on and recognition of these in their cultural contexts. In addition, there is a lack of validated psychometric assessments in Sri Lanka for measuring the emotional aspects of a person. To our knowledge, the only validated tool available to measure EI in Sri Lankans is specifically designed to be used among adolescents (Lankashini et al., 2017), making it unsuitable for assessing EI in adults. Therefore, it is important to identify, translate, and validate instruments for screening EI among the adult population of Sri Lanka.

1.4 Trait Emotional Intelligence Scale—Short Form (TEIQUE-SF)

TEIQUE-SF is a 30-item self-report measure of trait EI that was developed in 2009 (Petrides, 2009). It is especially recommended when a rapid assessment of the affective aspects of a person is required. TEIQUE-SF has shown good psychometric properties with discrimination parameters (Cooper & Petrides, 2010). It has been tested for validity in different settings and has been translated and adapted into more than 15

languages (London Psychometric Laboratory, 2022). TEIQue-SF is a psychometric tool that has been well researched and has demonstrated validity across populations. Therefore, the cross-cultural adaptation of this tool to Sinhala is useful as an initiative to observe emotional aspects among Sinhala speakers in Sri Lanka. After validation of the tool, clinicians can use it in clinical settings to obtain valid measurements of the emotional aspects of individuals.

2 METHODOLOGY

2.1 Translation

The TEIQue-SF was translated into Sinhala by the principal investigator, who is bilingual and fluent in both Sinhala and English, using the WHO guidelines for translating and adapting instruments (*WHO Guidelines on Translation and Adaptation of Instruments*, n.d.). The translator is a licensed clinical psychologist with an MPhil in clinical psychology and over a decade of experience working in clinical settings.

The tool was freely available on the TEIQue official website, with permission to be translated and adapted. Though special permission was not required for the adaptation, the author of the scale was duly informed about the intended study, and the permission was obtained. Linguistic and cultural factors were considered throughout the translation process, aiming to make language understandable for any person with an average level of literacy. Special efforts were made to ensure that the meanings behind the original items were preserved in the translation.

2.2 Expert Panel Evaluation

An expert panel of three, consisting of two clinical psychologists and a counseling psychologist, was asked to rate the translation in comparison to the original items on a Likert scale for clarity and relevance. The ratings ranged from least relevant to most relevant and least clear to very clear. A score of one was attached to a rating of least clear and least relevant, and a maximum score of five was attached to a rating of most relevant and very clear. Content validity index (CVI) values were calculated based on these ratings (Yusoff, 2019).

In addition to the ratings, the response form had a section for their comments and suggestions regarding each item. When items received low scores, the experts' comments were taken into consideration to verify the cross-cultural relevance of the items. Further discussions were held with the expert panel as well as language experts outside the expert panel, and the items were modified until the desired scores were obtained.

2.3 Comprehension Test

Since the efficacy of an instrument may differ between populations and in various cultures, the evaluation of the tool should be carried out in the population in which it will be used. Thus, a comprehension test was conducted to determine whether the translated scale was Comprehensible and acceptable. The validated scale is expected to be understood by individuals with average literacy for it to be feasible to use in research and by other professionals. Thus, fifteen adults who belonged to different educational backgrounds were recruited through convenient sampling to test the modified scale. The participants were residents of different areas of the Colombo district, and the majority of them were female. The age group of the participants was 22-60. Out of this sample, 05 participants were undergraduates, 04 were graduates, 02 were master's degree holders, 02 had completed the General Certificate of Education Advanced Level (G.C.E. Advanced Level), and 02 had the General Certificate of Education Ordinary Level (G.C.E. Ordinary Level) qualification. The expected average number of years of schooling in Sri Lanka, according to the Human Development Index (HDI), is 10 years. The G.C.E. Ordinary Level Examination is conducted in the 11th year. The two individuals with G.C.E Ordinary Level Examination qualifications were recruited to represent this average literacy level (United Nations, n.d.).

After the participants were informed of the purpose of the study and the adaptation process, written informed consent was obtained from each participant for the comprehension test.

A Likert-scale questionnaire, which included the title, instructions, response choices, and items of the TEIQue-SF Sinhala translation, was distributed among

the respondents. The respondents were instructed to rate each statement on a Likert scale of 1–5 on the ease of comprehension. The lowest level of comprehension was indicated by 01 (I did not understand anything), while level 5 (I completely understood) was the highest level of comprehension.

2.4 Back Translation

The services of a licensed translation company (We Translate PVT Ltd.) were obtained for the back translation. The researcher did not have any personal contact or discussion with the translator. A copy of the back translation was sent to the original author, requesting feedback.

2.5 Materials

The study was conducted in accordance with the ethical standards of the relevant institutional ethics committee. All study participants have granted their consent as per the institutional review protocols. At all stages of the adaptation, free Google forms were created to obtain ratings. Recruits who agreed to participate were sent the Google form link after obtaining informed consent. Whenever meetings were required, they were conducted online via Zoom. These measures were employed as the study was carried out during the COVID-19 pandemic.

3. RESULTS AND DISCUSSION

3.1 Translation and Expert Panel Evaluation

There were no changes applied to the TEIQue-SF original English format; only the content was translated without modifying the original English version.

When the translated draft was presented, modifications were proposed for six (06) items by the expert panel. In consultation with the expert panel, modifications were made to items without changing their semantic value. For example, the dictionary-translated Sinhala term for ‘perspective’ was formal and not in common usage. Thus, it was decided to explain the meaning of this formal term in semi-formal language within brackets after the formal term. The final decisions on the phrases and terms were made by consulting a professor of

Sinhalese from a state university, along with the panel of experts. In addition to this, there was an active discussion over several rounds about the equivalent Sinhala phrase for “trait emotional intelligence.” After presenting the translated version to the expert panel, CVI scores were calculated. The S-CVI score was 0.88. There was one item that received an ICVI of 0.3, while two items received an ICVI value of 0.5. Another seven items had received an ICVI value of 0.6. All other items received an ICVI value of 01. Items that received less than one were modified with expert suggestions.

3.2 Comprehension Test Results

All items had received a score of three or above on their level of comprehension. When the back translation was presented to the original author for feedback, the original author suggested no modifications.

During the adaptation process, the researchers faced a few challenges. TEIQue-SF is a model of emotion based on the Western cultural context. Western and Eastern cultural contexts appear to differ in terms of how they conceptualize and identify emotions. It was challenging to translate the English words denoting emotions into Sinhala. It was speculated that this may be because emotions are not very frequently discussed in the Sinhala cultural context. During the discussions held with the expert panel in deciding upon the final terms denoting emotions, the most frequent observation was that a single term may have multiple meanings and may be understood in different ways. Specifically, more than one Sinhala word was necessary to convey the emotions denoted by a single English word.

In addition, certain translated versions of the terms were too formal and were not in common usage. Therefore, careful consideration was required for the choice of words. Accordingly, the researchers had to make a special effort to find suitable Sinhala phrases and terms to generate the meaning provided on the original scale while achieving cultural relevance. It was difficult to select the appropriate words in Sinhala, as written Sinhala is different from spoken Sinhala. The suggestion of the expert panel on this matter was to incorporate a semi-formal language format. That way, it was expected to convey the meanings in a simple, well-understood written format of the language. It was

apparent from the comprehension test outcomes that the terms were well understood. It indicates that the process of adaptation, where choice of the words was considered with careful discussion and analysis, has yielded positive results.

3.3 Strengths and Limitations

The present study is an initiative to provide a tool that can be used to observe the emotional aspects of Sinhala speakers in Sri Lanka. Since the tool was not validated, its reliability and validity are limited. Future studies should focus on a complete validation of the tool to understand more refined psychometric properties of the TEIQue-SF Sinhala version.

The present study followed WHO guidelines for translating and culturally adapting instruments, which strengthens the results. However, despite the sample size for the pre-test being appropriate as per the guidelines, the small sample size should be acknowledged as a limitation since it limits the generalizability of the results. Future research should seek a larger sample size to increase the credibility of the results. Likewise, it needs to be acknowledged that all the participants were residents of the Colombo district. With respect to the cultural nuances of the Sinhala language, future studies could benefit from the inclusion of individuals from different regions of the country to apply the results to a broader context.

Practical Implications

Although emotional intelligence plays an important role in all areas of an individual's life, affecting their overall functionality and productivity, to the best of our knowledge, there is no standard tool to measure the emotional intelligence of adult Sri Lankans with an average literacy level. The translated TEIQue-SF showed high content validity and the comprehension test results indicated that the translated TEIQue-SF was easily understood by Sinhala speakers with an average education. Thus, the present study provides an easily understood psychometric tool, for obtaining measures related to the trait of emotional intelligence among Sinhala speakers. Upon validation of the tool, clinicians and other interested professionals could use it to obtain

valid measurements of the emotional aspects of individuals.

The current study describes the process of translation and cross-cultural adaptation of TEIQue-SF into Sinhala. It can be concluded that the Sinhala adaptation of the TEIQue-SF is appropriate to be administered to the Sinhala-speaking population with an average level of literacy. In the case of non-literate Sinhala-speaking populations, this can be interviewer-administered.

Ethics Statement

Ethical approval was obtained from the Ethical Review Committee of the Faculty of Medicine of KDU (**RP/2022/10**). The study was conducted in accordance with the ethical standards of the relevant institutional ethics committee. All study participants have granted their consent as per the institutional review protocols.

Source(s) of support

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Conflict of interests

There are no conflicts of interest.

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PADLET APP USES IN TESL: A SRI LANKAN EXPERIENCE

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ABSTRACT

Digital technology is found capable of playing a vital role in efforts to change from teacher-centeredness to student-centeredness in classroom management for TESL (Teaching English as a Second Language) by introducing autonomous learning strategies into the methodology followed. Therefore, integrating technology into TESL mechanisms is considered of paramount significance. In that context, Padlet is found usable as an efficient online app that can be used to boost active learning among students. Based on the results achieved in an experiment with a random group of 48 first-year Law undergraduates and 20 Computing freshmen at General Sir John Kotelawala Defence University who had been engaged in Padlet-based online learning activities in ESL for a period of four weeks, this paper analyses using SPSS 23.0 the data gathered in an online survey. Overall, the perceptions of the study population regarding the use of Padlet have been reported as positive. As revealed by the results, most of the participants (88.2%) were new to the use of Padlet app by the time it was introduced. Nearly, 79.4% of them identified that Padlet can make learning collaborative. In the meantime, 92.6% were convinced that Padlet is very influential in the process of knowledge sharing and 82.4% that it is a form of good motivation. Padlet has thus proven to be a very efficient tool in TESL. Hence, it is suggested here that it is important to include activities based on Padlet when designing curricula for teaching English as a second language.

KEYWORDS: Padlet, English language teaching, ESL learners, Online Education

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1. INTRODUCTION

Technological development in the modern era has greatly influenced many aspects of human life including health, education and industry (Bosamia, 2013). This has given birth to massive transitions in numerous human engagements. Education has become one of the core subjects of this novel change. The involvement of modern technology has drastically changed the traditional teacher-centred method of teaching to a more focused student-centred method of teaching. This has added new glamour to the art of teaching (Mascolo, 2009). The use of technology is a key factor behind developing independent learners as it makes the process of learning easy and comfortable. Modern research catering to English Language teaching has given greater focus to developing autonomous learners (Zaphiris and Ioannou, 2014). Therefore, integrating technology into English language teaching is of paramount significance.

As the world moves ahead with highly developed technology, there have been massive improvements concerning English Language teaching (Jana and Iveta, 2019). Therefore, the approaches utilized in English Language teaching have undergone tremendous changes. This has enabled language teachers to widen their scope of teaching beyond the context of a traditional classroom. The vast expansion of science and technology has heavily influenced the mechanisms used in language teaching and learning. Recent studies have discovered that integrating novel technology in the language classroom has turned out to be a leading factor that boosts the motivation of students. It encourages active learning and makes the students creative and efficient in solving problems (Stockwell, 2013). Bracewell & Sivin-Kachala & Bialo (2000) mentioned that technology has the potential to enhance students' self-concept and has a positive influence on achievements (Marleni, 2020).

As suggested by Watkins, the employment of novel technologies in the classroom can help the students intensify their learning experiences. Hence, modern-

day lecturers and teachers make numerous attempts to introduce novel mechanisms in teaching and learning the English Language (Watkins et al., 2007). As a result of these new approaches, the students increase their level of motivation. Further, it will enhance their level of autonomy in learning.

Padlet is a freely available web-based application that serves as a "wall" that gives access for the students to post pictures, words and videos. That can be seen and shared with others when the link is shared. Many researchers have highlighted the significance of the dawn of Web 2.0 in reinforcing collaborative practices. The web tools such as blogs and Facebook have proven to have a positive impact on language learning classrooms (Omar et al., 2012). During the e-learning classes, Padlet can be used very productively as a whiteboard. It can serve as a means of keeping records, giving feedback, reviewing, summarizing and applying the key points. Further, it can be utilized as a space for after-class activities. This allows the students to cooperate securely with an online community (Rashid et al., 2019).

As mentioned by Fageeh (2011), the students find the use of Padlet a comfortable means of learning. Further, he has reinforced the fact that Padlet becomes very useful for students when learning writing (Mohd Said et al., 2013). Besides, previous literature brings to light that Padlet is an efficient tool for improving the active learning of students. This also enables the students to sharpen their creative and critical thinking skills. In addition, there is a positive impact of Padlet in improving the level of achievement among students (Megat et al., 2020).

Researchers strongly believe that Padlet is an influential tool in the process of language teaching and learning. It is identified as an efficient means of practising in-class activities, especially concerning teaching writing. This plays a vital role in developing writing skills which is the core of language learning (Mahmud, 2019).

The Covid-19 pandemic has increased the affinity of students with the use of computers and mobile phones. Introduction of the distance learning has

made them highly attached to electronic devices. Even during this post-pandemic era, students often get distracted from their studies due to the influence of mobile phones and computers.

This new change has brought drastic changes in the teaching methods employed in language teaching. Further, this has increased the challenges come across by language teachers. Therefore, in this modern era, one of the most difficult challenges faced by language lecturers is the low levels of concentration among students. The high levels of their addiction to electronic devices make them distracted easily. Generally, young adults spend more than five hours a day with their mobile phones (Pratama, 2018). Further, this would result in poor academic performance among the students (Kuss and Griffiths, 2011). Hence, language lecturers must become strategic when planning their teaching approaches. Besides, it is necessary to use technology to keep the students engaged in language-related activities. Therefore, Padlet becomes a very useful tool in boosting the interest among students in language learning.

Padlet has become a prominent facilitator in developing interactive relationships between the lecturer and the student. Effective interaction of this nature helps in developing collaborative learning. This makes the lecturer become a facilitator rather than playing the traditional role of a teacher. Through Padlet the students can work together collaboratively with their colleagues. It creates a very comfortable environment for the students to share their attitudes and perceptions. Hence, Padlet becomes an excellent platform to enhance the student's exposure to collaborative learning (Mohd Said et al., 2013).

Therefore, Padlet has become an influential platform in the process of English Language teaching. This has been introduced to the context of Sri Lanka very recently with the outbreak of the Covid-19 pandemic. Hence, the knowledge and the use of Padlet among Sri Lankan students are limited. Furthermore, there have been many studies conducted all over the world to assess the effectiveness of using Padlet in language teaching among university students. However, there

is a dearth of studies conducted in the Sri Lankan setting. Hence, it is important to assess the students' perceptions about the use of Padlet in language learning and teaching in the higher education setting of Sri Lanka.

2. LITERATURE REVIEW

Padlet has gained recognition as an effective educational tool in various contexts, with multiple studies highlighting its potential benefits. A study carried out by DeWitt, Alias, and Siraj based on a group of 40 university students reveals that Padlet is used as an effective learning tool by university students (DeWitt et al., 2015). In addition, Awaludin, Abd Karim and Mohd Saad (2017) have conducted a study on the perspectives on Padlet among 30 Diploma in Accountancy students at University Technology MARA (UiTM), Tapah who undergo a compulsory English course. This study has also revealed that the students formed positive attitudes toward using Padlet in English writing class.

Moreover, Thomas, Morin and Ly (2015) have demonstrated through their research that the employment of technological tools in the classroom setting has the potential to improve the critical thinking skills of the students. It has also been revealed that when students are kept engaged in activities through technology-driven tools, they tend to become creative and critical in terms of their thinking (Mahmud, 2019).

Henry, Castek and Zawilinski, 2012, have revealed through research that students become capable of developing longer texts with the use of modern learning tools. This gives the students the necessary freedom and enthusiasm to revise and develop good writing (Henry et al., 2012).

As mentioned by Stannard, 2015, Padlet has become an efficient tool for keeping students engaged in brainstorming sessions, discussions, and project tasks (Haddad and Anggraini, 2021). Most importantly, the students get the ability to work with Padlet at their own pace. This provides the opportunity for the students to get involved in learning creatively without

the constraints of time and space. Using Padlet in English Language teaching is highly beneficial as it enables the students who are shy in class to be expressive. Besides, the lecturers also become comfortable as they can indicate their comments on the individual performance of the students. Hence, this improves the satisfaction and the interest of both the lecturers and students (Fadhilawati et al., 2020).

In addition, a study conducted in the UK concerning Bioscience and Dental undergraduates revealed that the majority of the students in both streams identified Padlet as an effective tool for promoting collaborative learning (Mehta et al., 2021).

A study carried out to investigate the students' perceptions of the impact of Using Padlet on Class Engagement revealed that Padlet enhances the students' level of engagement, and energetic learning and creates a highly favourable environment for learning. Moreover, it also promotes independent and collaborative learning (Nadeem, 2021). Another study has been carried out at Sultan Agung Islamic University among the students enrolled on an English Language Education programme. The study aimed to assess the perceptions of the students on the use of Padlet in the class Introduction to Functional Linguistics. The results of the study have revealed that the majority of the students were positive about the use of Padlet during their learning (Anwar et al., 2019).

Padlet is identified as one of the effective tools to be used in learning by DeWitt, Alias, and Siraj (2015) through their study findings. Moreover, Awaludin, Abd Karim, and Mohd Saad (2017) were able to engage in research on the use of Padlet by the ESL learners in their academic writing. Nevertheless, it has been identified that both the above studies were carried out with a participation of few students, therefore it is difficult to generalise the findings of those two studies to a large group of students. According to Thomas, Morin, and Ly (2015), the use of technology mediated teaching in the classroom can improve the critical thinking of the students. However, there is a gap which prevails in terms of identifying the precise methods and instructional

strategies in maximizing the potential benefits of those tools. In addition, Henry, Castek, and Zawilinski (2012) revealed that modern tools like Padlet have the ability to facilitate the student learning by helping them to develop longer texts and involve in revision. Nonetheless, there is a deficiency in the availability of experiential evidence concerning the long-term impact of such tools on writing skills. Moreover, there is a need for more inclusive research which caters to the engagement and adaptability of such tools in a wide range of learning environments.

3. METHODOLOGY

This study was conducted as a descriptive cross-sectional study. The sample size comprised forty-eight first-year Law undergraduates and twenty computing first-year undergraduates enrolled in General Sir John Kotelawala Defence University. The study sample was selected randomly, and they had been exposed to online education since the outbreak of the COVID-19 pandemic. The participants were subjected to four weeks of online learning activities through the Padlet App. After it was introduced, the students engaged in writing tasks, assignments and other group activities using Padlet. Further, the students were also allowed to collaboratively work with their colleagues using the Padlet. In addition, the students were able to get feedback from their peers and lecturers via Padlet. At the end of the four weeks, the students' perceptions regarding the use of Padlet were assessed. Since the data collection of the study was conducted during the outbreak of the COVID-19 pandemic an online questionnaire developed in English was shared with the selected participants to receive the completed questionnaires. The informed consent for attending the study was also taken online from the participants, once the purpose and the objectives were explained by providing an online information sheet before the questionnaire. The questionnaires did not consist of any sensitive questions which would create psychological embarrassment/ trauma for the participants. The participants were informed that they could leave the study at any time, and such departure from the study would not affect academic activities.

Moreover, all participants were informed that their participation was voluntary, and there were no incentives or rewards for their contribution to the study. Furthermore, the participants were empowered to make queries on the questionnaire by providing them with the contact details of the investigators. The researchers assured the participants that all gathered data from the participants would be kept confidential and not released in public under any circumstance. The soft copies of all the data were stored and protected with a unique password, and the hard copies generated were stored and kept locked in a secure place. After five years, all the data will be deleted to secure the participants' privacy and confidentiality.

The questionnaire consisted of questions related to demographic information and perceptions of Padlet. A questionnaire was piloted among ten University undergraduates to determine the difficulty level of the items, ease of understanding of concepts in the items, any discomfort when responding, and the appropriate length of the questions before the data collection. The students who participated in the pilot study were excluded from the main study. The SPSS 23.0 version was used for descriptive data analysis.

4. RESULTS

The mean age of the study population is 21.79 ± 3.73 and the majority of them were females (60.3%). Only 11.8% of the undergraduates had heard about the Padlet web app before it was introduced to them and 79.4% of the participants got to know about this app through university lecturers (Table 1).

When considering the perceptions of the study population on Padlet, 98.5% of the study participants were enjoying learning English via Padlet. The majority of the study population respectively agreed and strongly agreed that the Padlet is convenient for learning English and it makes the learning experience interactive (54.4%, 25.0%), that it helps to explore new information and share knowledge with colleagues (67.6%, 25%), that it makes the experience of distance learning very interesting

Table 1 -Socio-demographic data

Demographic characteristics		Sample (n= 154)	
		Frequency	%
Age		Mean = 21.79 SD ± 3.73 Range = 18 -37 years	
Gender	Female	41	60.3
	Male	27	39.7
Stream	Law	48	70.59
	Computing	20	29.41
Have you heard about Padlet before you began to use this in your English class?	Yes	08	11.8
	No	60	88.2
From where did you first hear about the Padlet?	University Lecturers	54	79.4
	Internet	12	17.6
	Other	01	1.5
	Friends	01	1.5

(60.3%, 26.5%), that it allows him/her to get engaged with his/her colleagues and lecturers with no restrictions of time and space (55.9%, 22.1%), that it is a good way of storing information for future use (66.2%, 20.6%), that it is an effective (63.2%, 30.9%) and motivational (61.8%, 20.6%) academic platform to conduct distance education, and that it is a good platform to learn English (61.8%, 27.9%) (Table 2).

Table 2: perception of Padlet

Item	Characterizes	Frequency	Percentage (%)
Do you enjoy learning English via Padlet?	Yes	67	98.5
	No	01	1.5
The use of Padlet makes the learning experience interactive.	Strongly Agree	21	30.9
	Agree	42	61.8
	Neutral	05	7.4
Padlet helps me share my knowledge	Strongly Agree	19	27.9

with my colleagues	Agree	40	58.8
	Neutral	09	13.2
Learning English via the Padlet is convenient for me	Strongly Agree	17	25.0
	Agree	37	54.4
	Neutral	13	19.1
	Disagree	01	1.5
Padlet helps me explore new information	Strongly Agree	17	25.0
	Agree	46	67.6
	Neutral	04	5.9
	Disagree	01	1.5
The use of Padlet makes the experience of distance learning very interesting	Strongly Agree	18	26.5
	Agree	41	60.3
	Neutral	09	13.2
Padlet allows me to get engaged with colleagues and lecturers with no restrictions on time and space.	Strongly Agree	15	22.1
	Agree	38	55.9
	Neutral	15	22.1
I am willing to use Padlet in my future studies	Strongly Agree	14	20.6
	Agree	43	63.2
	Neutral	10	14.7
	Disagree	01	1.5
Padlet is an effective platform for academic studies done via distance education	Strongly Agree	21	30.9
	Agree	43	63.2
	Neutral	04	5.9
I feel motivated when using Padlet during the lectures	Strongly Agree	14	20.6
	Agree	42	61.8
	Neutral	12	17.6
Padlet is a good way of storing information for future use	Strongly Agree	14	20.6
	Agree	45	66.2
	Neutral	09	13.2
Padlet is a good platform for learning English	Strongly Agree	19	27.9
	Agree	42	61.8
	Neutral	07	10.3

5. DISCUSSION

The current study aimed at assessing the perception

of the web application ‘Padlet’ among first-year undergraduates at General Sir John Kotelawala Defence University, Sri Lanka. The results of the study were categorized into key themes developed out of the responses received through the questionnaire. Motivation and Engagement, Interactive Learning and Collaboration and Convenience and Practicality were the major themes identified. The above themes have the potential in providing valuable insights into the usage of Padlet in the classroom setting.

The findings of the study revealed that majority of the study sample enjoy learning English through the use of Padlet. A similar study conducted in Indonesia (Anwar et al., 2019) and Egypt (Nadeem, 2021), indicated that the Padlet has the potential to enhance the motivation and the engagement of the students.

However, a study conducted by Mahmud (2019) in Malaysia revealed that Padlet has no significant impact on improving the writing skills in English. The participants of the current study identified Padlet as an effective tool with regard to learning English, knowledge sharing and engaging in academic activities. Therefore, the findings of the study align with the broader literature available on the effectiveness and the practicality in the use of technology-enhanced learning tools.

The findings of the present study appear to be similar to the previous studies conducted in Indonesia and Egypt. However, Mahmud in his study conducted in Malaysia highlighted on the significance of context-specific research in assessing the efficiency of Padlet.

Further, it has been noted that the nature of the activities given to the students and the English language proficiency of the students will also contribute to the students’ experience when using Padlet. The positive attitude among the students regarding the use of Padlet can lead to enhanced motivation and interactive learning in a classroom setting. It will create a favourable environment for cooperative learning. However, the teachers need to make sure that they create tailor-made Padlet activities to cater to the specific learning objectives.

Conclusion, Recommendations and Limitations

The findings of the current study have emphasized the perceptions of the first-year undergraduates at General Sir John Kotelawala Defence University, Sri Lanka with regard to their experience in using the web application 'Padlet.' It was evident that Padlet has proven to bring a positive experience for the students in the ESL context. Motivation, interactive learning, convenience, and collaborative opportunities were identified as key themes derived from the findings of the study. Although the findings of the current study become similar to the previous research conducted in similar settings, it is necessary to conduct further experimental research to understand the context-based differences in the use of Padlet.

The high level of students' satisfaction when using Padlet reveals that it has the potential to enhance the students' enthusiasm in learning. Moreover, the high degree of flexibility and convenience of Padlet with regard to time and space contribute substantially for its success as an educational platform. In addition, Padlet helps in promoting interactive and collaborative learning, making the language learning and teaching a promising experience for the students and teachers. Nevertheless, it is necessary to investigate the use of Padlet in diverse educational contexts and among students of different levels of English language proficiency. It will facilitate in making conclusions that are applicable to a more generalized population. Hence, it is recommended to integrate the use of Padlet based activities into teaching practice catering to the specific learning objectives and desired outcomes. Further, educators can engage in different experimental activities by using Padlet to enhance student motivation and collaborative learning in ESL context. Moreover, including the use of technology driven activities into the curriculum will expose the students into valuable skills of the modern generation.

The findings of the study contribute to the current discourse on integrating technology into education. Moreover, it brings to light the potential benefits of using Padlet as an effective learning tool in English language classroom.

One of the limitations of the present study is that it has been carried out in a specific educational context where the English language proficiency of the students remain at a satisfactory level. Therefore, the findings of the study will not be able to apply for a generalized population.

In addition, the current study does not aim to investigate the long-term impact on the use of Padlet. Therefore, further experimental research is needed to explore the sustainable use of Padlet over a considerable period of time. Further, it is also important to understand the potential challenges in using Padlet in ESL context. Despite the aforementioned challenges the present study contributes to highlight potential benefits of using Padlet as an effective study tool in a ESL setting.

Data Availability

The data used to support the findings of this study are available with the corresponding author upon request.

Conflict of Interest

All authors declare that they have no relevant conflicts of interest.

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EVALUATING OCCUPATIONAL RADIATION EXPOSURE IN INTERVENTIONAL CARDIOLOGY: AN INVESTIGATION INTO ESTIMATING EFFECTIVE DOSE

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ABSTRACT

To safeguard the safety and well-being of interventional cardiology healthcare workers, monitoring their occupational radiation exposure is crucial. This study evaluates the radiation dose of interventional cardiologists using the Swiss Ordinance for personal dosimetry approach. Its primary aim is to estimate the radiation dose for each operator engaged in interventional cardiology procedures to protect from dangerous levels of radiation. Additionally, this study assesses the correlation between under-apron and over-apron dosimeters. Notably, no previous studies in Sri Lanka have specifically assessed radiation dose in this context, making this research vital in shedding light on radiation exposure in an interventional cardiology environment. Two cardiologists conducted a total of 108 interventional cardiology procedures, including coronary angiograms and percutaneous coronary interventions for a month at the cardiac catheterization laboratory of Sri Jayewardenepura General Hospital, Sri Lanka. Active dosimeters were utilized to measure dose values using a two-dosimeter approach where one dosimeter was positioned above the thyroid collar and the other beneath the lead apron on the left side of the waist. The effective doses (E) were determined using the Swiss Ordinance algorithm. Furthermore, this study also examined the relationship between under and over-apron dose values. The Swiss Ordinance algorithm estimated the mean annual E values for each cardiologist, resulting in 3.0397 mSv/year and 0.9697 mSv/year, respectively showing that the estimated annual occupational doses remained well below the annual dose limit (20 mSv/year). The accuracy of the algorithm in interventional ionising radiation scenarios was also highlighted. A strong positive correlation ($R^2 = 0.9500$) was observed between over-apron and under-apron dose values. Applying the Swiss Ordinance for personal dosimetry and studying the link between over and under-apron dosimeters in interventional cardiology improve our grasp of radiation dosimetry. Emphasizing precise dose estimation for the safety of cardiologists, this study enhances the radiation safety practices in interventional cardiology.

KEYWORDS: *Effective Dose, Double Dosimetric Algorithm, Interventional Cardiology, Occupational Exposure, Radiation Protection, Swiss Ordinance for Personal Dosimetry*

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1. INTRODUCTION

Fluoroscopy-guided interventional cardiology is a rapidly developing medical field focused on diagnosing and treating cardiovascular diseases. Within this field, procedures involving fluoroscopy-guided cardiac catheterization have proven highly advantageous for patients. However, a significant concern arises around potential radiation risks for medical professionals involved in these procedures. This concern is particularly relevant to interventional cardiologists, who work in close proximity to patients within radiation fields that can be irregular and scattered. Prolonged and close exposure to such conditions can result in higher cumulative radiation doses for medical staff over time. Consequently, it is imperative to implement adequate measures to safeguard the health of healthcare workers. To minimize radiation exposure, protective equipment like lead aprons and thyroid shields play a pivotal role in interventional cardiology. Lead aprons offer protection to critical organs such as the lungs and reproductive organs, while thyroid shields are designed to shield the neck and thyroid gland. Beyond relying solely on protective gear, cardiologists should adopt safe radiation practices. This involves limiting their time spent in radiation-prone areas, maintaining distance from radiation sources, and utilizing shielding methods (Balter, 1993; Biso and Vidovich, 2020; Valentin, 2006; Ramanathan, Almeida and Fernando, 2021).

An essential tool for ensuring radiation safety is determining the effective dose (E), which quantifies the absorbed radiation energy in the body, accounting for the type and sensitivity of exposed tissues and organs. This measurement helps to evaluate potential health risks and the necessity for additional protective measures. Typically, E is calculated and reported when significant radiation exposure occurs. The International Commission on Radiological Protection (ICRP) recommends whole-body dose limits of 20 mSv/year averaged over a defined 5-year period. It is emphasized that the E should not exceed 50 mSv in any single year for healthcare workers with occupational exposure, aiming to prevent adverse health effects. Regular monitoring of radiation levels and individual doses assists in identifying areas requiring heightened

protection and assessing the effectiveness of current safety protocols (López *et al.*, 2018).

To estimate radiation dose accurately, the operational quantity Hp(10) is employed, representing the dose at a 10 mm depth in soft tissue. Dosimeters, coupled with protective equipment, are vital for precise monitoring and reducing exposure levels. For interventional cardiology units with high radiation doses, the ICRP advises the use of two dosimeters. One dosimeter is placed beneath the lead apron to measure the absorbed dose, while the other is positioned above the apron to gauge ambient radiation levels. This approach provides a reliable estimation of the E (Vano *et al.*, 1998). However, it is important to acknowledge that dosimeters positioned beneath lead shielding can sometimes miscalculate the E due to the protective effect of the shielding. Placing a dosimeter in front of the lead garment can lead to an overestimation of the dose. To address this issue, a common strategy involves using a single dosimeter reading adjusted by a correction factor. Nevertheless, for greater accuracy, a method involving two dosimeters is preferred. One dosimeter is positioned beneath the shielding garment, and the other is placed above it. This dual dosimetry approach enhances the accuracy of energy determination by combining both measurements in a linear manner (Von Boetticher, Lachmund and Hoffmann, 2010; Kuipers *et al.*, 2008). Despite these benefits, some concerns have been raised regarding the use of two dosimeters, including the potential for them to be swapped or forgotten by medical professionals. Acknowledging the real-world limitations of using only a single dosimeter in certain interventional cardiology units, this study focuses on evaluating the correlation between dosimeter measurements taken directly above the apron and those obtained beneath the apron. This assessment aims to provide valuable insights into radiation exposure and safety within the field.

In Sri Lanka, the regulatory bodies responsible for radiation protection have adopted a method for calculating the E in interventional cardiology procedures, as proposed by the National Council on Radiation Protection and Measurements (NCRP). However, this method has certain limitations. It does not account for protective measures like lead thyroid

shields, and it does not take into consideration the specific energy spectrum of the radiation being measured. In response to these shortcomings, the current study has turned to the Swiss Ordinance Personnel dosimetric method to address these issues more effectively (Abdelrahman *et al.*, 2020; Baechler *et al.*, 2006). The Swiss Ordinance method offers a more comprehensive solution by addressing the concerns mentioned above. It proposes a dual dosimetric approach that provides a more accurate estimation of the E. Among the various algorithms available for double dosimetry in radiation measurement, the decision to use the Swiss Ordinance method was based on its ability to yield accurate and thorough results, especially when only Hp(10) dosimeters are available in cardiology departments. By implementing the Swiss Ordinance dosimetric method, the aim of this study is to overcome the limitations posed by the NCRP double dosimetric method. The goal is to ensure a more comprehensive and accurate assessment of radiation exposure for international cardiologists working in interventional cardiology settings. It is worth noting that the accuracy of this algorithm has been validated by various studies, confirming its performance within the recommended uncertainty ranges.

This study focuses on assessing the annual occupational radiation exposure of interventional cardiologists using the Swiss Ordinance method for personal dosimetry. The main objective is to estimate the radiation dose that interventional cardiologists are exposed to over a year and to evaluate the correlation between dosimeters positioned below and above the protective apron in order to determine the reliability of utilizing a single dosimeter. This approach is being investigated for its effectiveness in estimating radiation dose levels. The purpose of this estimation is to ensure that these medical professionals are not subjected to hazardous levels of radiation during their work and use. Given the absence of prior research in Sri Lanka concerning the evaluation of radiation dose specifically for interventional cardiologists, this study aims to fill this knowledge gap. It aims to shed light on the extent of radiation exposure in the unique working environment of interventional cardiology. By gaining a more

comprehensive understanding of radiation levels, the research intends to pave the way for implementing appropriate measures that will effectively safeguard the health and well-being of these healthcare workers.

2. METHODOLOGY

In this study, a total of 108 interventional cardiology procedures were performed during a month. These procedures included 78 Coronary Angiograms (CA), and 30 Percutaneous Coronary Intervention (PCI) procedures. However, no cardiac implantation and electrophysiology procedures were included due to the limited number of procedures conducted during the data collection period. The research project received approval from the institutional ethics committee, ensuring that it met ethical guidelines. All participants involved in the study provided their informed consent, indicating their full understanding and agreement to take part. The procedures were conducted by two cardiologists identified as operators A and B. All procedures in Cath Lab were performed using ceiling-mounted Philips Allura FD 10 C-arm (Philips Medical Systems, Best, the Netherlands) equipped with a 1024x1024 matrix, 1250 mA at 80 kV, standard Fluro, and cine acquisition frame rate with 7.5 and 15 frames/sec, respectively for CAs and PCIs. This study excluded procedures that deviated from the standard acquisition protocol in terms of magnifications and frame rates in order to prevent any potential bias in the results caused by non-standard acquisitions. Both operators used wraparound lead aprons with an overall lead equivalence of 0.25 mm at 50-110 kVp during all interventional cardiology procedures. The wrap-around apron had an overlay due to which the real lead apron thickness in front is 0.5 mm lead equivalent. Both operators wore 0.5 mm Pb neck collars. Operator A used 0.5 mm Pb equivalent eye goggles during their procedures. The Cath Lab had 0.5 mm ceiling-mounted Pb shields for additional protection.

In this study, active dosimeters were utilised to measure the estimated E values. Two Hp(10) active dosimeters, specifically the PM1610 model from Polimaster in Austria, were employed to gather dose measurements. The PM1610 dosimeter employs a Geiger-Muller tube to detect radiation. Calibration of the PM1610 device

was conducted using ^{137}Cs sources and a plane parallel PMMA phantom measuring 30x30x15 cm. The measurement range for the dose equivalent rate (DER) varied from 0.1 $\mu\text{Sv/h}$ to 10 Sv/h. The calibration of the device assembly is accurate within $\pm 6\%$ at a confidence probability of 0.95. For continuous photon radiation, the measured DE range was 0.05 μSv to 10.0 Sv, while for pulsed photon radiation; it was 10 μSv to 10.0 Sv. The accuracy of DE measurement was $\pm 20\%$, and the detector's energy range was 0.02 to 10.0 MeV.



Figure 01: Hp(10) dosimeter positioned above the thyroid collar.

For the double dosimetric approach, dose measurements were obtained using two Hp(10) dosimeters. One dosimeter was positioned above the thyroid collar on the left side of the neck (Figure 01),



Figure 02: Hp(10) dosimeter positioned under the lead apron

while the second dosimeter was placed underneath the lead apron on the left side of the waist (Figure 02). Before obtaining the actual dosimeter measurements, the background radiation dose was consistently measured. The E was estimated using double dosimetric algorithms suggested by Swiss ordinance on personal dosimetry where a thyroid shield was used.

$$H_{total(10)} = H_{under(10)} + \alpha * H_{over(10)}(01)$$

where $H_{under(10)}$ is the equivalent dose reading of the under-apron and $H_{over(10)}$ is the equivalent dose reading of the over-apron dosimeter. The value of the weighting parameter $\alpha = 0.05$ when a thyroid shield is used. The recorded background doses were subtracted from the measurements of the over and under-apron doses. E per CA and PCI procedure for each operator was also estimated.

To contrast the doses measured above and below the apron, given the availability of just one Hp(10) dosimeter in the cardiology unit, a basic linear regression analysis was carried out. The Wilcoxon ranked test was used to analyse the difference between over and under-apron doses. All statistical computations were performed using the software Statistical Package for the Social Sciences (SPSS) version 26.0. The significance threshold was established at a value of $p < 0.05$.

3. RESULTS

The number of procedures performed over a month by the A and B operators was 65 and 43, respectively. Operator A performed 40 CAs and 25 PCIs. Operator B performed 35 CAs and 8 PCIs.

Table 01 shows the mean, standard error of the mean, median, standard deviation, minimum, maximum, and sum of the estimated E per year for all the procedures, annual estimated E per procedure of CA, and annual estimated E per procedure of PCI. Figures 03 and 04 visually illustrate the distribution of annual estimated E values, as well as the estimated E values per individual CA and PCI procedure.

These figures provide a graphical representation of how these values are spread across the two operators being studied.

Table 1: Mean, standard error of the mean, median, standard deviation, minimum, maximum, and sum of the estimated E (mSv) per year for all the procedures, annual estimated E (mSv) per procedure of CA, and annual estimated E (mSv) per procedure of PCI.

Estimated E per Year (mSv)						
	Mean	Std. Error of Mean	Median	Std. Deviation	Minimum	Maximum
A	3.0397	0.6086	1.3932	4.5543	0.2171	22.1774
B	0.9697	0.1717	0.4282	1.2499	0.0714	6.8958
Estimated E per CA per Year (mSv)						
	Mean	Std. Error of Mean	Median	Std. Deviation	Minimum	Maximum
A	0.3675	0.0388	0.3200	0.2363	0.0340	0.9678
B	0.1754	0.0207	0.1378	0.1344	0.0181	0.5814
Estimated E per PCI per Year (mSv)						
	Mean	Std. Error of Mean	Median	Std. Deviation	Minimum	Maximum
A	2.4148	0.4953	1.5191	2.1591	0.0866	8.8724
B	0.7511	0.1375	0.6761	0.4560	0.2553	1.7508

Graph 01

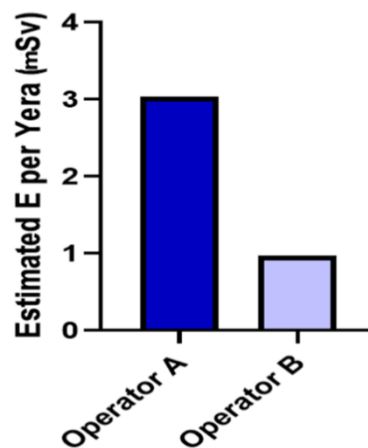


Figure 03: Distribution of the annual estimated effective doses (E) for operators A and B

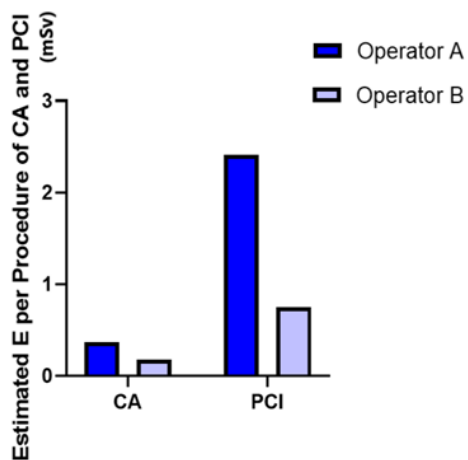


Figure 04: Distribution of estimated effective doses (E) for the procedure of CA and PCI for operators A and B

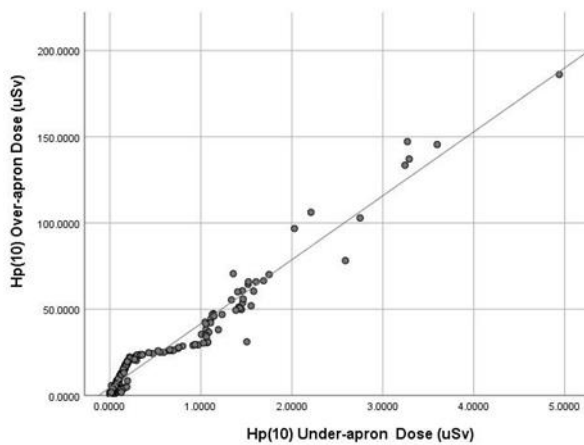


Figure 05: The relationship between the estimated effective doses (E) (μSv) obtained from the over and under-apron doses obtained within a one-month duration.

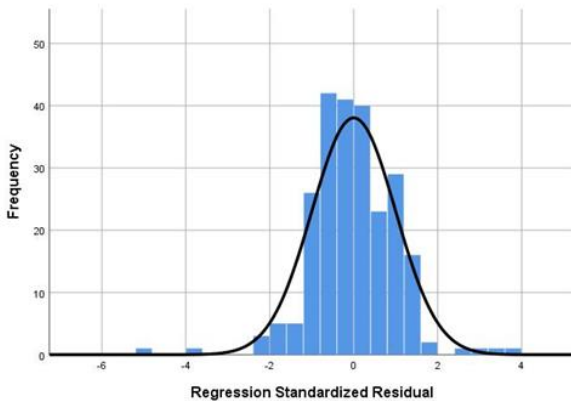


Figure 06: The distribution of standardized residuals from the linear regression.

Upon evaluating the relationship between dose values taken above and below the apron, the regression analysis revealed robust and positively inclined linear connections ($p < 0.001$, ANOVA) ($R^2 = 0.9500$). Figures 05 and 06 visually depict the connection between the dose measurements obtained from over and under the apron, alongside the distribution of standardized residuals from the linear regression, respectively. The Wilcoxon signed-rank test was employed to investigate the statistical significance in the comparison of recorded shielded and unshielded dose readings. The results of the test validated a

statistically notable distinction between these two measurements ($p < 0.05$, Wilcoxon ranked test).

4. DISCUSSION

The utilization of the double dosimetric algorithm proposed by the Swiss ordinance on personal dosimetry, as demonstrated by several studies (Baechler *et al.*, 2006; Jossen *et al.*, 2003), has proven to be a reliable approach for assessing radiation exposure. The current findings of the study, which indicate that the calculated dose values remain well below the stipulated annual dose limit of 20 mSv/year, highlight the effectiveness of this algorithm in accurately estimating radiation doses. Moreover, the congruence observed between the estimated E values obtained from the Swiss ordinance on the personal dosimetry algorithm and the outcome of our study reinforces the robustness of this approach. This alignment between theoretical estimations and empirical data further substantiates the algorithm's credibility in practical radiation exposure assessments. The endorsement of the Swiss Ordinance algorithm by Järvinen *et al.* (2008), following a meticulous evaluation of various double dosimetry algorithms, underscores its superior accuracy in predicting effective doses, particularly in scenarios involving interventional ionizing radiation. The ability of the algorithm to mitigate both overestimation and potential underestimation, particularly when relying solely on Hp(10) dosimeters, adds to its utility and reliability in diverse radiation exposure scenarios. In essence, the empirical evidence and expert validation provided in this study collectively affirm the efficacy of the Swiss ordinance on personal dosimetry algorithm, thereby establishing it as a valuable tool for accurate radiation dose assessment across a spectrum of practical applications.

Operator A obtained the highest annual estimated E values from the algorithm, most likely because they carried out the greatest number of cases, specifically 65 procedures. Likewise, it is evident that Operator A encountered higher radiation doses during each individual CA and PCI procedure. These procedures encompassed both fluoroscopic imaging and Cine imaging. Notably, Cine imaging emits approximately

10 times more radiation than fluoroscopy (McKetty, 1996). Consequently, the variance in annual estimated E values between Operator A and Operator B could be attributed to multiple factors. These factors encompass the number of procedures conducted, the intricacy of said procedures, discrepancies in operational methods, and variations in expertise and proficiency among operators. In essence, a higher radiation exposure of operator A is likely a result of a combination of these variables (Kicken *et al.*, 1999; McKetty, 1996; Vano *et al.*, 1998).

The study uncovered strong connections between the readings of dosimeters placed in an unshielded manner (without any protective covering) and those placed with shielding (protected by a lead covering) ($R^2 = 0.9500$). This finding suggests that a single dosimeter positioned above the thyroid collar can effectively provide an accurate measurement of radiation exposure for medical personnel working with interventional cardiology. This eliminates the need for an additional dosimeter placed under the lead apron, which is typically used for shielding against radiation. Similar research conducted by Kuipers *et al.* (2008), Dalah *et al.* (2018), and Moladoust *et al.* (2015) also yielded comparable results, reinforcing the idea that a single dosimeter placed above the protective thyroid collar is sufficient for accurate dose assessment in fluoroscopy scenarios. However, an important finding emerged from the Wilcoxon signed-rank test, which highlighted significant differences between the direct readings of dosimeters placed with shielding and those placed without. This indicates that these two measurements are not interchangeable. In other words, the protective barrier of the lead apron does influence the radiation dose recorded by the dosimeter underneath it. The research by Moladoust *et al.* (2015) cautioned against swapping measurements between shielded and unshielded positions based on this significant difference. This underscores the importance of maintaining consistency in the approach to radiation dose assessment. Such consistency is crucial to prevent potential health risks for medical personnel who are routinely exposed to radiation, as inaccuracies in dose measurement could have negative consequences for their well-being.

The annual estimated radiation exposure for each operator was calculated considering the medical procedures they performed within the current hospital setting. It is worth noting that both operators involved in this study have the potential to carry out a greater number of CAs and PCIs in their private practices. In light of this possibility, it becomes necessary to account for the radiation doses they would receive during these additional procedures performed in their private practices. Therefore, for a comprehensive and accurate assessment of the annual radiation exposure for each operator, it is essential to include the dose values received by both operators during their private practice procedures as well.

5. CONCLUSION

The integration of the Swiss Ordinance for personal dosimetry brings about significant consequences in the field of radiation dosimetry, marking a substantial advancement in our comprehension of this complex discipline. This regulatory framework goes beyond merely highlighting its importance; it emphasizes the utmost importance of meticulously selecting methods to achieve accurate and reliable estimations of radiation doses, particularly in the context of Sri Lanka.

The study brought attention to the dependability of using a single dosimeter positioned above the thyroid collar for the purpose of estimating radiation dose. The finding underscores the trustworthiness of this approach in accurately gauging radiation exposure. Nonetheless, it is worth noting that the study also revealed noteworthy disparities between the measurements of radiation dose taken when a shielding barrier was in place and when it was not. In other words, the presence or absence of shielding, such as a protective apron, had a discernible impact on the recorded dose measurements. The results obtained from the study provide validation for the practice of utilizing dosimeters positioned beneath lead aprons when conducting measurements, even though there are inherent challenges associated with employing two dosimeters simultaneously. The findings of the study offer substantial evidence to justify the continued use of dosimeters under lead aprons for accurate

measurements, even considering the difficulties posed by the use of two dosimeters in such scenarios.

To sum up, the adoption of the Swiss Ordinance for personal dosimetry as a double dosimetric approach has far-reaching implications for the field of radiation dosimetry. Its primary focus on precisely estimating radiation doses not only underscores its significance but also establishes a fundamental basis for refining safety protocols. This, in turn, cultivates a culture centred around precision and well-informed decision-making. Through the implementation of this regulatory framework, the field takes a significant stride forward, not only in enhancing our theoretical knowledge but also in ensuring practical applications that prioritize the health of individuals and the broader environment.

6. ACKNOWLEDGEMENT

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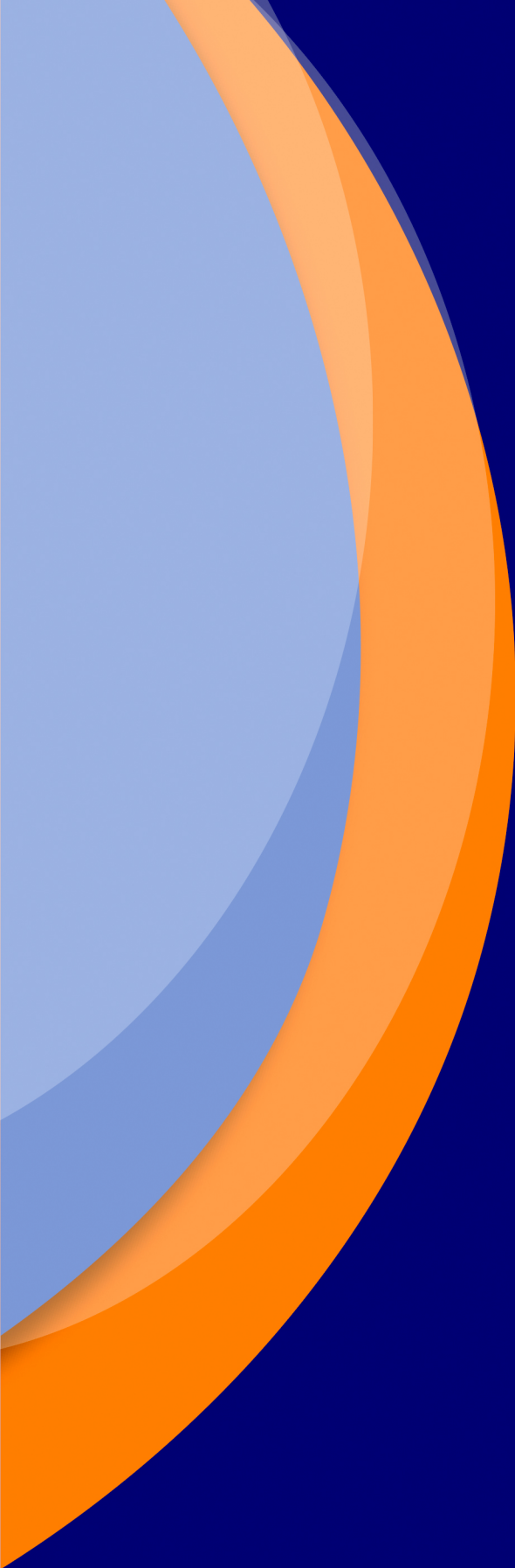
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