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Panel of Reviewers

Editorial Note - Journal of Tropical Environment

I am pleased to present Volume 3, Issue I & II of the *Journal of Tropical Environment*, a biannual publication dedicated to advancing scholarly discourse on environmental management, particularly within tropical ecosystems. The journal embraces an interdisciplinary approach, drawing from natural sciences, social sciences, management, and philosophy to address the pressing environmental challenges of our time. Main focus remains on research that engages with the complexities of managing tropical environments, encouraging innovative perspectives that span traditional academic boundaries. This issues showcase a diverse range of articles that have undergone a rigorous double-blind peer review process, ensuring the highest standards of scholarly integrity.

I extend my heartfelt gratitude to the authors, reviewers, and editorial board members, whose expertise and commitment have been crucial to the success of this journal. Their contributions have ensured that the *Journal of Tropical Environment* continues to be a valuable resource for researchers and practitioners alike. I hope this issue will inspire meaningful dialogue and inform sustainable development initiatives across both public and private sectors.

Prof. DMSLB Dissanayake - Editor in Chief
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JOURNAL OF TROPICAL ENVIRONMENT

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Department of Environmental Management
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Sri Lanka

Changes of Water Usage Sources in a Cascaded Tank Village System (CTVS) : The Case Study from Kapiriggama

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Abstract

This study investigates the dynamics of water usage and its changing patterns within the Cascaded Tank Village System (CTVS) in Kapiriggama, which is situated within the Rambewa Secretarial Division of Anuradhapura District in Sri Lanka. The study covers three Grama Niladhari Divisions: Kapiriggama, Peenagama, and Konakumbukwewa. It specifically investigates factors driving changes in water use, the appropriateness of water sources, and ways of promoting the adoption of safe and sustainable usage of water. A mixed-method approach was adopted, drawing on primary data from a questionnaire survey of 291 randomly selected households, and secondary data sources. It emerged from the analysis that domestic wells were the main source of water for daily activities, whereas alternative sources like tank water and tube wells were not as utilized. Results indicate a lack of proper pattern in the use of water among the villagers and a lack of awareness in measures that could help avoid waterborne diseases, which may be increased due to climate variability, attitude, population growth, development pressures, and an increasing prevalence of chronic kidney disease. The study recommends targeted interventions, including the promotion of proper practices of water use, increasing the public's awareness of the consumption of safe water, and financial investments in infrastructure development. These measures are essential for ensuring sustainable water resource management and improving the quality of life in the Kapiriggama area.

Key words: Cascaded Tank Village System, Kapiriggama, sustainable water resources, water quality, water usage patterns

1. Introduction

Water resource management is an important aspect of rural development, especially in regions reliant on traditional systems such as the CTVS. The CTVS is a unique agrarian water management system that has supported livelihoods and increase the agricultural water productivity (Sirimanna & Prasada, 2021) for rural communities in Sri Lanka for centuries. In Sri Lanka's dry zone, human-made tanks have been utilized for over 2,000 years to collect, store, and distribute rainfall and runoff, serving as a vital source of irrigation water for paddy cultivation(Bebermeier et al. , 2017). A tank cascade is a hydrologically interconnected network structure of clustered tanks. Madduma Bandara (1985) coined the term "tank cascade" to describe the network of small tanks connected to a large tank below existing even at present in Sri Lanka. He also provided the following definition for the tank cascade as: *"A cascade is a connected series of tanks organized within a micro-(or meso-) catchment of the dry zone landscape for storing, conveying and utilizing water from an ephemeral rivulet"* (Madduma Bandara, 1985) A cascade in the dry zone is made up of about 4 to 10 individual small tanks with each tank having its own micro-catchment, but all of the tanks are situated within a single meso-catchment basin. These meso-catchment basins could vary in extent from 6 to 10 sq. miles, with a modal value of 8 sq. miles in the North Central Province(Panabokke et al., 2002).

However, during the last few decades, the system has encountered serious challenges from changes in the pattern of water use and quality of water(Abeysingha et al., 2021), climatic variability, and socio-economic transformations(Wickramasinghe et al., 2023). These threaten the very sustainability of the system and the livelihoods of communities dependent on it (Dharmasena, 2020). The Kapiriggama area in the Rambewa Secretarial Division of Anuradhapura District is a representative case to investigate the complex nature of change in water use within a CTVS. The study area consists of three Grama Niladhari Divisions, namely, Kapiriggama, Peenagama, and Konakumbukwewa, where the people use various sources of water, including domestic wells, tank water, and tube wells to fulfill their daily requirements. However, there is no orderly pattern in the use of these sources, which may lead to inefficiency and health risks(Abeysingha et al., 2018).

Water-use patterns in rural systems have changed significantly due to various socio-economic and environmental factors. Changes in water use in the Kapiriggama CTVS are influenced by population growth, urbanization, development pressures, and the increasing chronic kidney disease prevalence in the area. Climate change has also further exacerbated rainfall variability, which in turn has disrupted water availability and distribution. These challenges outline the need for understanding the dynamics of water usage and the implementation of effective sustainable water management strategies to safeguard traditional systems while adapting them to contemporary needs. In the case of Kapiriggama, the community, like most rural communities in Sri Lanka, traditionally relied on tanks and communal wells prior to the 1970s. The Kapiriggama CTVS still functions today, providing services to the community. In spite of that, human-made activities and natural factors have conspired to bring a change to the sources of water exploited. In effect, it follows that the usage pattern has become increasingly disorganized with no structured or sustainable practice in place. This study explores the changing pattern of water use in the Kapiriggama CTVS and identifies the drivers of such changes and evaluates their impacts on the community. Some key research questions include:

i. How do changes in water-use patterns affect the community, and do these changes contribute to an unstable living environment?
ii. Are the people in the community exposed to unexpected physical, social, economic, and environmental shocks based on the changes?
iii. What are the main drivers behind the change in water use patterns?

Through this, the research addresses what are the causes of change in water use, assesses what those changes mean for the community, and suggests how the community can promote sustainable and safe water practices.

Objectives of the study

This study aims to examine the evolving patterns of water usage in a Cascaded Tank-Village System (CTVS).

The specific objectives are as follows:

i. To evaluate the availability and distribution of various water sources in the study area.
ii. To investigate the underlying causes of changes in water usage patterns within the CTVS.
iii. To assess the potential for encouraging the adoption of high-quality water sources and correcting unsustainable water usage practices in the study area.

2. Methodology

The research was carried out in three *Grama Niladari* (GN) Divisions: Kapiriggama, Peenagama, and Konakumbukwewa, within the Rambewa District Secretarial (DS) Division in the Anuradhapura District. Overall, the sample size used for the study consisted of 291 households, with 145 respondents from Konakumbukwewa, 83 from Peenagama, and 63 from Kapiriggama. The study relied heavily on primary data, supported by secondary data to provide complementary insights into sources of water use in other locations. Primary data collection was done through:

1. Interviews: Structured and semi-structured interviews with residents for qualitative information.
2. Field Observations: Observation of actual water use practices and site conditions.
3. Questionnaires: Administered surveys to gain quantitative data on water consumption patterns and preferences.

As shown in figure 1, this holistic approach allowed the study to capture the source contributions to water use and the dynamics of change in sources in the study area. The collected primary data and secondary data were analyzed by using both qualitative and quantitative methods. All analyzed data were presented by using graphs and appropriate text.

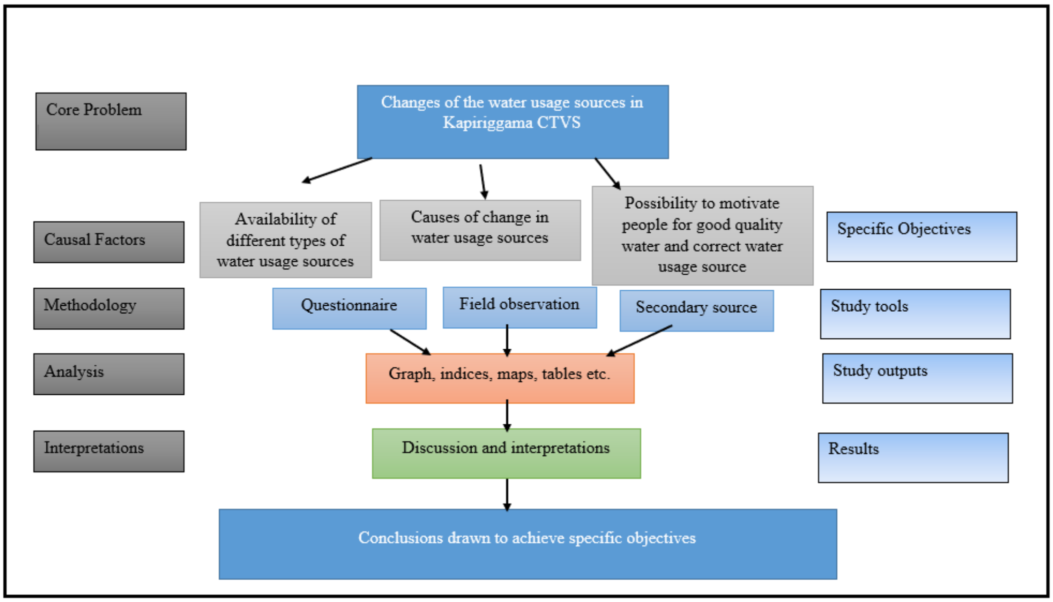

Figure 1: Summary diagram of a methodology

Study Area

As illustrated in Figure. 2 the study area is located in the Anuradhapura District of the North Central Province of Sri Lanka. It is hydrologically very important that this area is located near the Malwathu Oya and Ma Oya watershed boundary area. Kapiriggama is located in the Malwathu Oya basin. It comprises of 21 small irrigation tanks and one medium irrigation tank. The Kapiriggama comes under the DL1b agro-ecological zone. It has a bi-modal rainfall pattern with distinct rainfall peaks from March to May and October to December. The average annual rainfall in DL1b agro-ecological zone is above 900 mm. The cascade is comprised of three *Grama Niladhari* Divisions, namely Kapiriggama, Peenagama, and Konakumbukwewa. The total irrigable area of the cascade is about 500 ha.

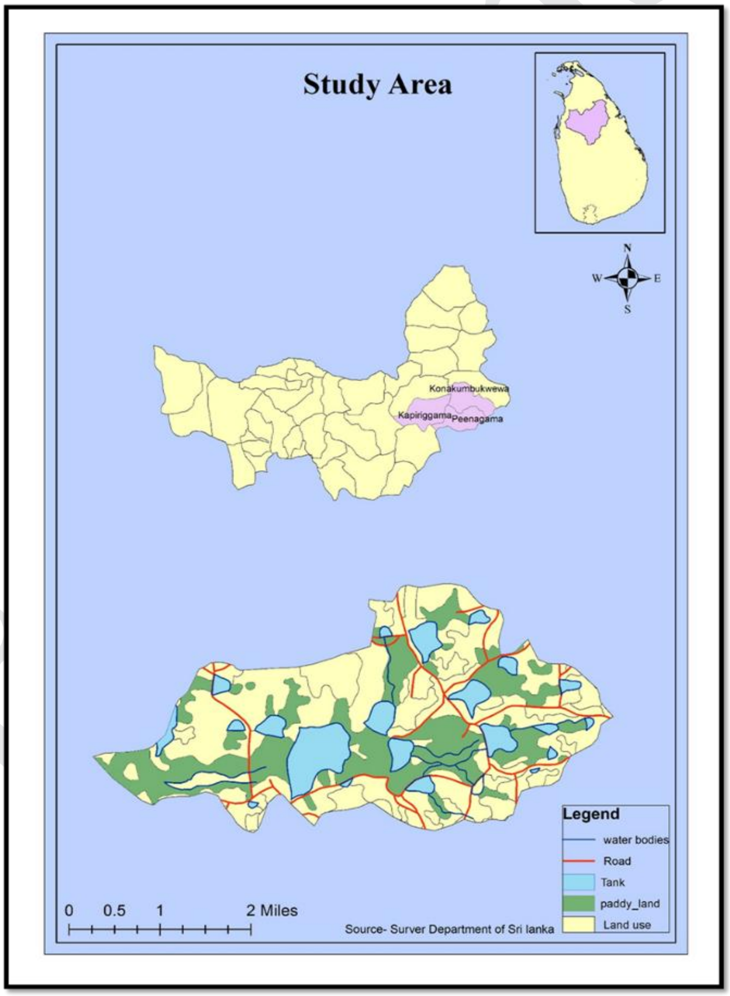

Figure 2: Study area

3. Results and Discussion

This section consists of various findings from the study in relation to the interaction existing between the research objectives and the developing trend of water use in the Kapiriggama CTVS. This section interprets data collected from the study area, highlighting key findings and discussing implications in the context of rural water resource management. The results and discussion are therefore presented under the following main subsections for clarity and systematic exploration:

3.1. Water usage patterns and sources in the study area

Water is the very essence of life(Kılıç, 2020), comprising a large part of the biological makeup of animals, plants, and human beings; without sufficient water, life would not exist(Żeber-Dzikowska et al., 2022). In rural settings, water is vital for essential activities such as drinking, cooking, washing, agriculture, and livestock management. Inadequate access to water significantly affects rural communities, whose livelihoods depend on agriculture, cattle rearing, and home gardening. Furthermore, water, sanitation, and health are interconnected, and equitable access to water has emerged as a critical issue, particularly in rural Sri Lanka.

As depicted in Figure. 3 usage of various water sources as perceived by the people in Kapiriggama CTVS regarding various uses. As explained by the highest bars in the graph, from this graph, it is clear that among the different purposes, well water is mostly utilized by people for kitchen use, toilet use, and cloth washing purposes. The water in the tank, though used for multiple purposes like bathing, washing clothes, cattle drinking and plantation, is less frequently utilized compared to the domestic well water, especially for tasks related to kitchen use and toilet use.

Other sources like agro wells, Rain Water Harvesting System (RWHS), tube wells, and others show a very negligible usage. For instance, tank water is mainly utilized for bathing, followed by plantation and washing clothes. Agro wells and tube wells are less used across the activities, which indicates lower dependency on these sources to satisfy the water requirements of the area.

This distribution of water source usage clearly shows that the community's reliance is on domestic wells and tank water for their daily activities, while other sources like tube wells and agro wells are relatively underutilized. The findings suggest a possible opportunity for better management and distribution of water resources, especially in promoting tank water utilization and exploring the potential of rainwater harvesting and other sustainable water systems.

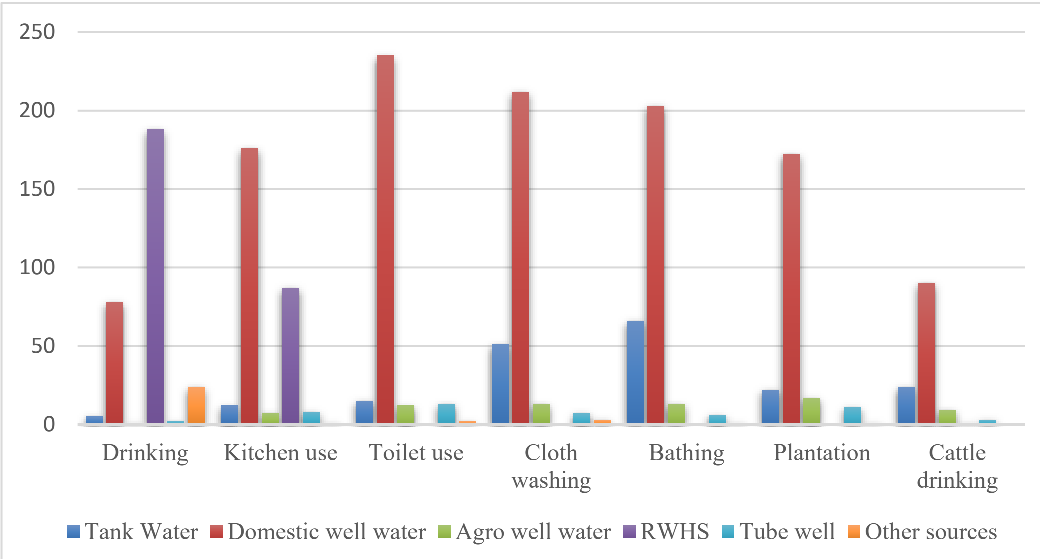

Figure 3: The usage of sources for water needs of the people in the study area
Source: Field survey data

Drinking water usage sources

Figure 4 highlights the distribution of sources of drinking water usage in the Kapiriggama CTVS. Domestic well water is the most utilized source for drinking water, as it accounts for the largest portion of 176. This would indicate a high reliance on domestic wells by the local population for their drinking water needs.

Where water from a tank, despite being traditionally a more important source, is not as heavily relied on for drinking, recording a total of only 12 cases. Even in a small amount, only 8 instances are supported by RWHS, while agro well water contributes merely 7, thus defining its minor contribution to the household's needs. The very minor contribution can be found with tube wells or any other source.

These results are indicative of the importance of the tank water within various utilizations by the community but pinpoint domestic well water as a principal source of drinking water. It is in these matters that research into further improvement and sustainable quality control of the domestic wells might be urged, besides exploiting the opportunities of enhancing the RWHS and other alternative sources for the supply of water as drinking water in pursuit of its security and sustainability.

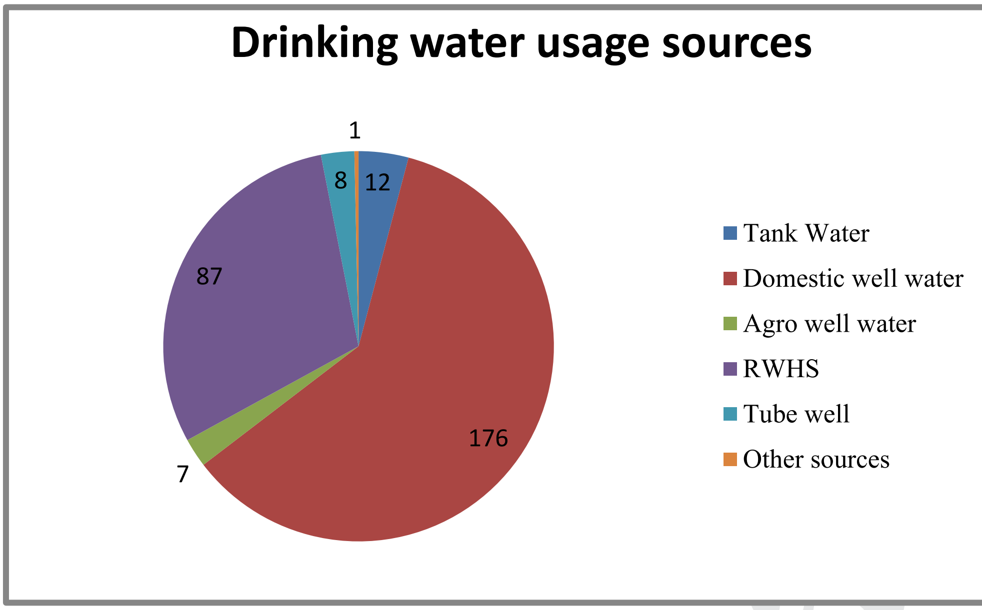

Figure 4: The usage of sources for water needs of the people in Kapiriggama
Source: Field survey data

The study area has 21 tanks, 291 RWHS, 300 domestic dug wells, and 25 agro wells. The majority of households were depending on unsystematic drinking water sources, such as domestic dug wells, agro wells, and tank water, according to the perceptions of local residents. In contrast, more suitable drinking water sources, such as rainwater and alternative sources like reverse osmosis (RO) plant water and bottled drinking water, are used by only 30% of the population. The remaining 70% of households still use less suitable drinking water sources.

Historically, tank water was the main source of drinking water for the majority of the population in the dry zone. With time, however, the community dependence on the village tank became lessened because of several households adapting different water collection approaches and alternative sources, like domestic wells and tanks. This change was influenced by many factors that include population growth, expansion of the urban area, development of infrastructure, and anthropogenic and natural influences like climate change. These factors have driven a shift in the sources of drinking water outside the CTVS.

3.2. Causes of changes in water usage patterns within the CTVS

Changes in water use patterns within the CTVS have resulted from a set of interacting factors, which have varied over time. These include anthropogenic drivers like population growth, urbanization, and agricultural practice change, as well as environmental ones, such as climate variability and alteration of the natural water cycle. The change in water use patterns reflects the broader socio-economic and environmental changes that have redefined traditional water management practices in the area. The section examines the major drivers behind these changes, providing insight into the complex dynamics which have influenced the availability, accessibility, and quality of water sources within the CTVS.

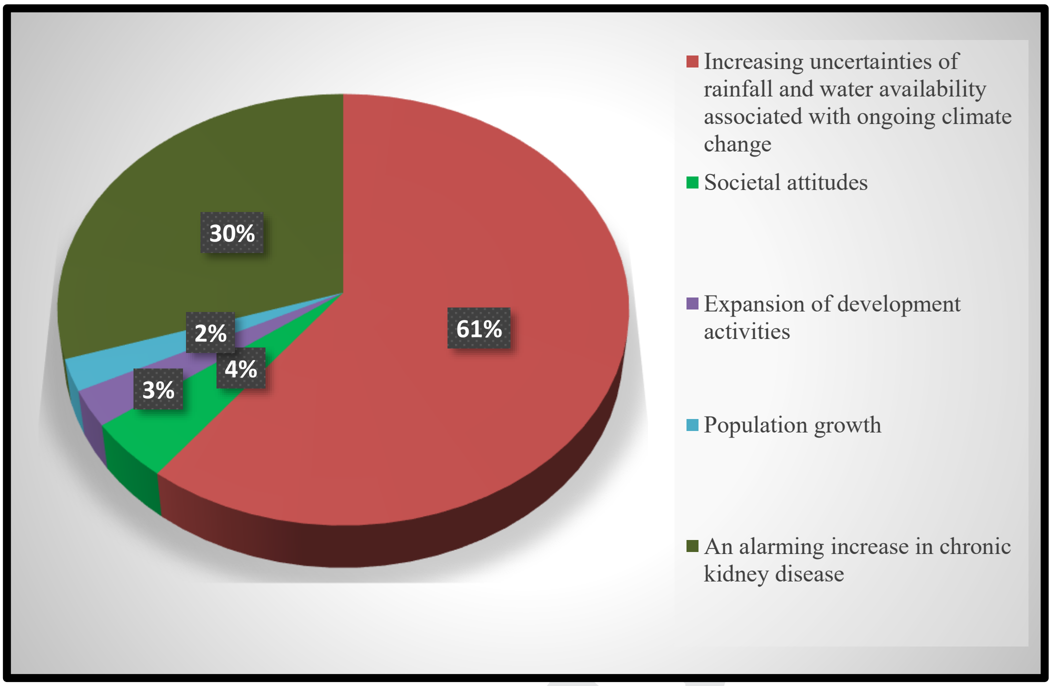

Figure 5: Reasons for changing the water usage sources in the Kapiriggama CTVS
Source: Field survey data

As illustrated by the figure 5, causes for changing water sources in the CTVS, the most influential factor of change in water sources is increasing uncertainties of rainfall and water availability from continued climate change, comprising 61% of the responses. This indicates the severe impact of climate variability on water resources and how such has forced households to find other means of getting water. Other contributing factors include alarming increase in chronic kidney disease at 30%, reflecting a change in perceptions and preferences of usage, possibly due to the evolving concern over water quality and convenience. The societal attitudes and increase in development activities contribute 4% and 3%, respectively, which shows that there was some impact from urbanization and, demographic pressure on changing sources of water.

These findings reflect the complex interplay of environmental, social, and health-related factors that have shaped changing water use patterns within the village tank system, signaling a need for adaptive strategies in sustainable and safe water management for the future.

3.3 Potential for encouraging the adoption of high-quality water sources and correcting unsustainable water usage practices in the study area

Analysis by available data shows some major findings of the study, which estimated the potentiality of encouraging adoption to high-quality water source and correcting unsustainable usages of water in the study area. About 70%, according to the study, depended on unsuitable water sources; this population made use of domestic dug wells, agro wells, and tank water unsystematically for drinking. This reliance on inadequate water sources poses significant risks to health and sustainability, especially in the context of ongoing climatic uncertainties and the increasing population.

The study also indicates an increasing shift towards more suitable water sources such as RWHS systems and other reliable options like RO plant water and bottled drinking water, but only 30% of households have adopted these higher-quality sources. This disparity could therefore mean that the adoption rate is relatively low, and sensitization and development of infrastructure should be encouraged if more widespread use of these sustainable water sources is to be achieved.

These findings have pointed towards the need for a multifaceted approach to encourage people to use high-quality water sources and change unsustainable practices. It would also involve:

- *Raising awareness:* Educate communities about health risks from using poor-quality water sources and the benefits of switching to rainwater harvesting, RO plants, or other safe sources.
- *Enhancing climate resilience:* Developing strategies to adapt to the uncertainties of climate change by promoting efficient techniques of water conservation, thus enhancing local water management practices.
- *Health implications:* Addressing the alarming increase in chronic kidney disease, the possible health benefits of switching to higher-quality water sources are highlighted.
- The overall study indicates that while better water source adoption is possible, much policy, education, and infrastructural effort needs to be in place for the widespread adoption and sustainability of water use in the study area.

4. Conclusion and Recommendations

The findings of this study have pointed out considerable challenges and opportunities related to water use in the CTVS of the study area. The key issue remains a predominant reliance on unsystematic and poor-quality water sources, such as domestic dug wells, agro wells, and tank water, on which 70% of households depend for drinking water. This trend has huge health and sustainability implications, especially with the increasing unpredictability of rainfall patterns and water availability as dictated by climate change. Despite better alternatives like rainwater harvesting systems and advanced treatment methods such as RO plant water, only 30% of households use them, which signifies that there is still a huge gap between availability and adoption.

The analysis revealed that the primary factors influencing changes in water usage practices include the increasing uncertainty in water availability due to climate change (61%), alarming increase in chronic kidney disease at (30%), and the expansion of development activities. Population growth and societal attitudes changes were also identified as important contributing factors. The previous scenario indeed specifies that the improvement of the sustainability in water practices in the area must come up not just in infrastructural challenges but equally in societal attitudes toward its usage.
The following recommendations are proposed in view of the findings and discussions to improve water quality, ensure sustainable usage practices, and handle some key issues identified:

- *Promotion of awareness and education programs:*

  These would involve public awareness campaigns in educating communities on the use of high-quality water sources, such as rainwater harvesting and purified water, to reduce health risks associated with unsystematic water usage. This should also include information about the linkage between poor water quality and diseases such as chronic kidney disease.

- *Encourage investment in water infrastructure:*

  Households should be incentivized through financial and technical support to invest in various water management solutions, such as rainwater harvesting systems, filtration unit installations, and RO plant water. The local authorities can help by providing access to low-interest loans or subsidies in order to lower the financial barriers for these investments.

- *Develop climate-resilient water management strategies:*

  In view of this high vulnerability of water due to climate change, there is a need to develop and implement strategies for climate-resilient water management. This should include water conservation, enhancement in storage capacity, such as that of tanks and RWHS, and integration of recent technologies to optimize water availability during scarce periods.

- *Strengthen local water management institutions:*

  Local water management institutions, such as community-based water management committees, should be empowered to oversee the equitable distribution of water, with emphasis on adhering to sustainable practices. This could be one of the most important committees in the regulation of water source utilization and the distribution of new technologies related to the same.

- *Implement health monitoring and interventions:*

  With the alarming rise in chronic kidney disease, health monitoring programs should be installed by the government and local health authorities to trace the affected people due to waterborne diseases and provide them with essential medical interventions. A study on the correlation between water quality and the incidence of kidney disease in the region could be beneficial for targeted health policies.

- *Support behavioural change:*

  Society's attitudes towards water saving and utilization of higher orders of treatment should be changed. This will be developed through social marketing, community-based activities, and case studies presentation on households or villages that shifted to the more valuable alternatives.

While the study has indicated continued dependence on unsystematic water sources in the study area, it also highlights opportunities for improving water usage practices. Addressing the root causes of water shortage, health risks, and the general attitude of society may facilitate the adoption of improved water sources. Education, investment in infrastructure, climate resilience, health interventions, and a change in policy are needed to ensure sustainability in water resources within the CTVS. The recommendations above are supposed to assist policymakers, development organizations, and local communities in making the transition toward more sustainable and health-conscious water usage practices in the CTVS.

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GIS-Based Spatial Analysis for Landfill Site Selection in Udunuwara, Sri Lanka

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Abstract

Inadequate land availability for waste disposal presents a major challenge for many developing countries, including Sri Lanka. The rapid urbanization of Udunuwara, a Divisional Secretariat in the Kandy District, has intensified this issue, highlighting the need for a suitable landfill site to support effective waste management. Improper disposal practices can lead to severe environmental, economic, aesthetic, and public health consequences. This study aims to identify a landfill site for Udunuwara that is economically viable, environmentally sound, and socially acceptable. A GIS-based spatial analysis combined with Multi-Criteria Decision Analysis (MCDA) techniques was employed to determine the most suitable location. Nine spatial data layers were prepared based on their relevance: slope, elevation, rivers, roads, towns and villages, public and religious places, land use, and geology. Criteria parameters were derived from an extensive literature review. Two MCDA techniques: Simple Additive Weighting (SAW) and the Analytic Hierarchy Process (AHP) were implemented in ArcGIS to generate a suitability index map. These results were integrated to produce the final landfill suitability map.

The study area was classified into five categories: unsuitable (30%), less suitable (28%), moderately suitable (21%), suitable (15%), and most suitable (6%). One candidate site was recommended for landfill development, and its suitability was examined in detail. Additional potential areas were also identified. To validate the results, comprehensive field surveys and ground-truthing are strongly recommended prior to implementation. This integrated approach can significantly contribute to resolving the waste management challenges in Udunuwara and support sustainable environmental practices.

Keywords: Landfill, GIS, MCDA, AHP, SAW

1. Introduction

Municipal Solid Waste (MSW) includes all solid waste generated from domestic, industrial, commercial, institutional, and construction activities (Mallick, 2021). Effective solid waste management is essential at all administrative levels to ensure public health and environmental protection. Factors such as population growth, rising living standards, and industrialization have led to a significant increase in global waste production (Alkaradaghi et al., 2019). The waste management process typically comprises four main stages: generation, collection, transportation, and disposal. Various disposal methods are in practice, including open dumping, sanitary landfilling, composting, incineration, anaerobic digestion, and others (Mallick, 2021).

The issue of solid waste management is particularly acute in developing countries, which comprise approximately 80% of the global population (Alkaradaghi et al., 2019). In countries like Sri Lanka, unscientific waste disposal practices are often prevalent due to rapid urbanization, population growth, and a lack of public awareness. These challenges have led to increased daily waste generation and associated environmental and health risks, including groundwater contamination via leachate, air pollution, and methane emissions (Mussa & Suryabhagavan, 2021). Moreover, improper waste disposal results in aesthetic degradation and poses significant public health concerns. Studies have linked proximity to dumpsites with a range of health effects, such as reproductive disorders, low birth weight, congenital malformations, respiratory issues, and cancer (Dissanayake & Dissanayake, 2015; Mallick, 2021).

Sri Lanka faces similar challenges. The Gohagoda dumpsite in Kandy has been operational for over 15 years, creating a foul odor and rendering the surrounding area uninhabitable. Its associated leachate has polluted local groundwater, and nearby housing projects have failed as a result. The Meethotamulla dumpsite disaster on April 14, 2017, exemplifies the risks of mismanaged waste sites; a slope failure at the site resulted in 32 fatalities and the destruction of 145 houses and other infrastructure. These incidents underscore the urgent need for scientifically designed and properly located sanitary landfills.

While numerous studies have been conducted to identify suitable sanitary landfill sites at the municipal level, there is a lack of research addressing solid waste disposal at the Pradeshiya Sabha (local authority) level. In the present study area, the existing dumpsite is situated on steep terrain, making it unsuitable for continued use. Therefore, this research aims to identify a scientifically appropriate location for a sanitary landfill that addresses current environmental and structural concerns.

In Sri Lanka, open dumping remains the most common waste disposal method due to its ability to accommodate large volumes of waste. However, it is associated with severe environmental and health hazards, including water pollution, air contamination, and associated diseases (Jayawardhana et al., 2015). In contrast, sanitary landfilling offers a more sustainable and environmentally responsible alternative. A sanitary landfill is a controlled and engineered disposal system designed to minimize environmental impact (Chu, 2008). Nevertheless, the success of such systems depends heavily on proper site selection.

Selecting suitable sanitary landfill sites is a complex, multi-criteria process that must account for environmental, social, economic, hydrological, and geological factors. Despite the urgency, Sri Lanka has seen limited efforts in this area, particularly at the local level. This study addresses this gap by establishing relevant criteria and parameters for sanitary landfill site selection in a Pradeshiya Sabha area. It employs spatial analysis and Geographic Information Systems (GIS), alongside Multi-Criteria Decision Analysis (MCDA) techniques specifically the Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW) to evaluate critical factors. By comparing the results of these methods, the study aims to generate a comprehensive land suitability map and recommend the most appropriate sanitary landfill site. Ultimately, the research seeks to serve as a valuable reference for future waste management planning efforts in similar contexts.

2. Aims and Objectives

The primary aim of this study is to identify suitable sanitary landfill sites through an integrated and systematic approach. To achieve this, both primary and secondary data sources were utilized, ensuring a comprehensive understanding of the spatial, environmental, and socio-economic context.

The study is guided by four main objectives, each further supported by specific sub-objectives designed to address different aspects of the landfill site selection process.

A structured methodology was developed to ensure analytical rigor. This involved the application of GIS-based spatial analysis and Multi-Criteria Decision Analysis (MCDA) techniques, specifically the Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW) methods. These tools enabled the evaluation and integration of multiple spatial criteria relevant to sanitary landfill site selection.

The key outcome of the study is the development of an Overall Suitability Map, which delineates varying degrees of land suitability across the study area. Based on this map, potential candidate sites for sanitary landfilling will be identified through detailed land suitability analysis, integrated within the broader analytical framework.

Ultimately, the study seeks to develop a conceptual framework that facilitates the identification of sustainable and scientifically appropriate sites for sanitary landfilling. Figure 1 presents the conceptual framework that underpins this research approach

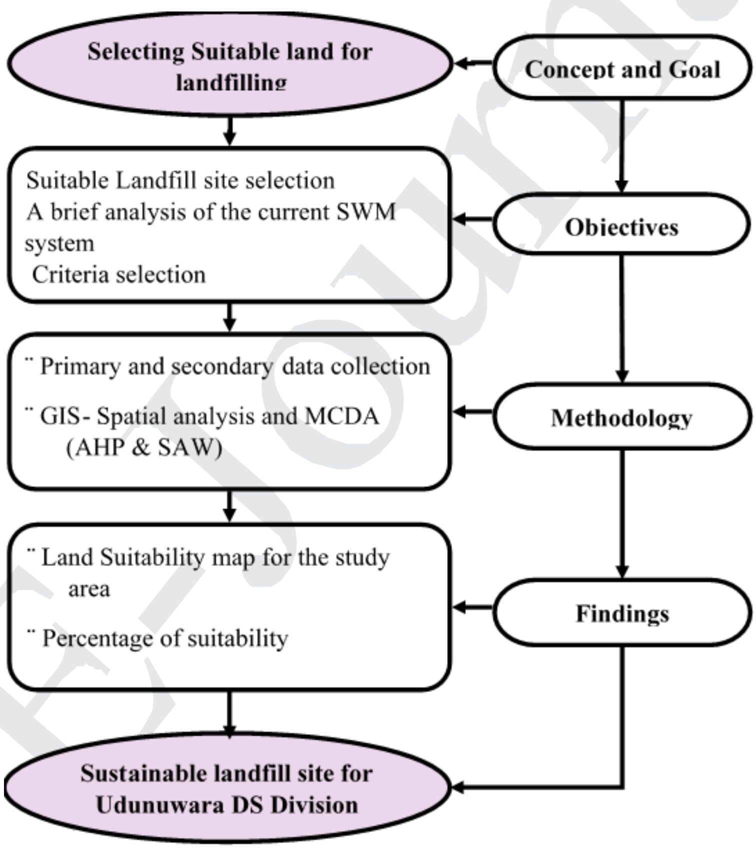

Figure 1: Conceptual Framework

3. Methodology

3.1. Study Area

The study area is the Udunuwara Divisional Secretariat in Kandy District (Figure 2), Central Province, Sri Lanka, covering 65.8 km² with a population of 121,360. Located in the wet zone, Udunuwara experiences a tropical climate with an average annual rainfall of 3,175 mm and temperatures ranging from 21°C to 26°C, occasionally reaching 29°C–30°C during dry periods. Elevation varies between 178 and 800 meters, contributing to a complex terrain.

Soil types include Reddish Brown Lateritic soils, Regosols, Alluvial soils, Immature Brown Loams, and Red-Yellow Podzolic soils, influencing land suitability for waste management. The land is mainly used for agriculture and commercial purposes.

Currently, waste is disposed of through open dumping, leading to environmental and health issues. Given the area's terrain and land use, identifying a suitable sanitary landfill site is essential for sustainable waste management and minimizing ecological impacts.

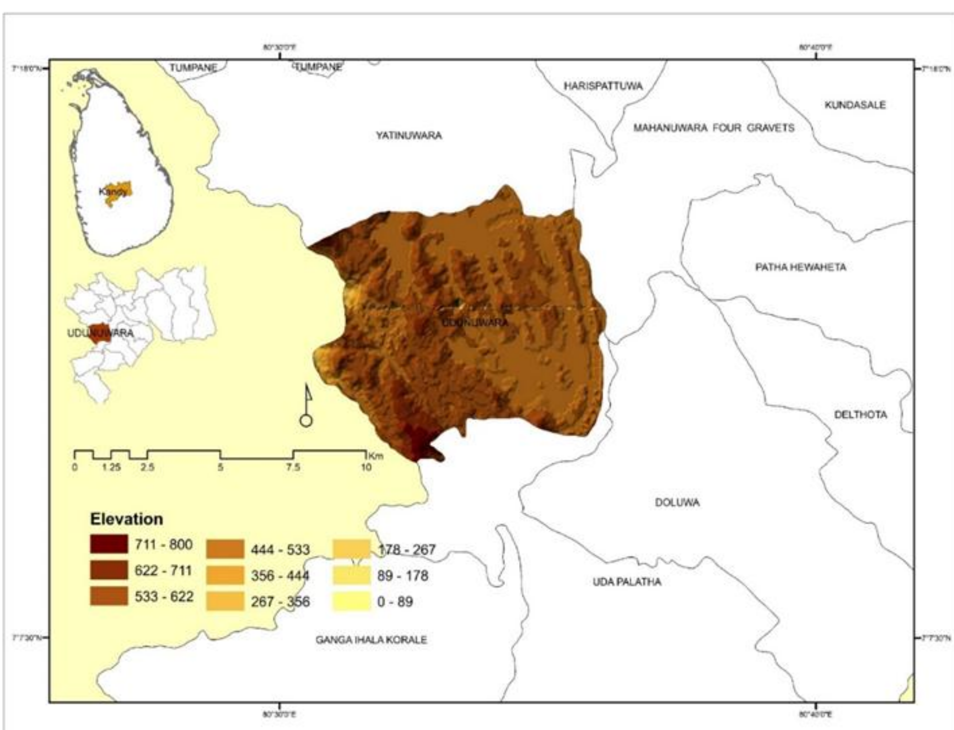

Figure 2: Study Area Map

3.2. Data Collection Methods

This study employs both primary and secondary data collection to achieve its objectives.

3.2.1. Primary Data Collection

Primary data were gathered through field observations and non-structured interviews with key stakeholders to understand the current solid waste management practices in the Udunuwara DS Division. Due to COVID-19 restrictions, interviews were conducted both in-person and via phone calls. Interviewees included local authority officials such as the municipal mechanical engineer from Kandy Municipal Council, officers from the Central Environment Authority (Polgolla), and officers from Udunuwara Pradeshiya Sabha. In total, five interviews were conducted. Additionally, direct observation of the Kiriwaula dumpsite provided insights into existing waste disposal methods.

3.2.2. Secondary Data Collection

Secondary data were sourced from academic publications, government reports, Kandy land use maps, digital topographic maps (1:50,000 scale, maps 54 and 61), the Kandy Digital Elevation Model (DEM), and GIS platforms such as Google Earth Pro and Open Street Map. These data were used to build a comprehensive spatial database for analysis.

3.3. Data Analysis

Data validity was ensured through GIS-based spatial analysis, which integrated diverse spatial datasets within a unified platform. Factors influencing sanitary landfill site suitability were grouped into two categories: natural environmental factors (elevation, slope, rivers, and geology) and built-environment factors (villages, towns, public and religious places, land use, roads, and commercial buildings). A total of nine thematic maps were created for further analysis.

Multi-Criteria Decision Analysis (MCDA) Techniques

Two MCDA methods were applied to evaluate the suitability criteria:

i. **Analytic Hierarchy Process (AHP):**

AHP involves pairwise comparisons of criteria using a scale from 1 (equal importance) to 9 (extreme importance). After normalization, relative weights were assigned to each factor.

The Weighted Linear Combination (WLC) method in GIS was then used to calculate the suitability index**.**

ii. Simple Additive Weighting (SAW):

SAW ranks criteria based on weighted averages. Weights were normalized by dividing each criterion's weight by the sum of all weights. The suitability index was computed using a standard formula.

The suitability maps generated from AHP and SAW were combined with equal (50:50) weighting to produce the final suitability map. The results are thoroughly analyzed, and the study concludes with recommendations and discussion of limitations.

For a visual overview of the methodology, see Figure 3

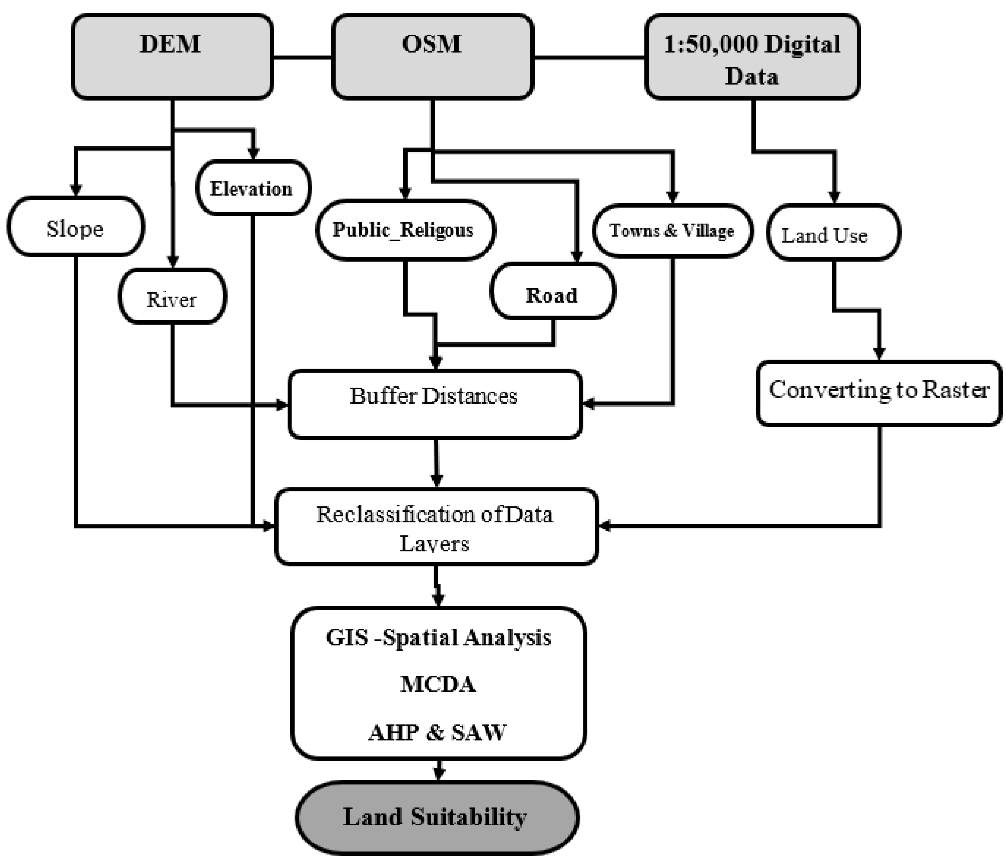

Figure 3: Overall Methodology

3.3. Criteria Selection for a Suitable Sanitary Landfill Site in Udunuwara DSD

Selecting a suitable sanitary landfill site in Udunuwara Divisional Secretariat Division requires a comprehensive evaluation of environmental, social, and economic factors. These criteria are grouped into two main categories: natural environment and built environment.

i. Natural Environment Criteria

Key factors include proximity to rivers, geological conditions, slope, and elevation. These influence the protection of surface water and aquatic ecosystems from contamination. Due to the risk of leachate leakage, sites near rivers are carefully assessed to prevent water pollution. Elevation and slope are important for mitigating flooding risks, ensuring efficient waste transportation, and preventing soil and water contamination in low-lying areas.

ii. Built Environment Criteria

This category considers land use patterns, proximity to villages and towns, public and religious places, and road accessibility. Landfills must maintain adequate distances from public and religious establishments to minimize impacts such as noise, odor, water contamination, and visual disturbance. Similarly, buffer zones around residential and urban areas help protect public health, local economies, and aesthetics.

Land use is critical in site selection; unsuitable areas such as water bodies, urban zones, and forests are excluded, while barren lands, shrub lands, and rocky areas are preferred. Distances from urban areas follow regulatory standards and expert guidance to accommodate future urban expansion and safeguard community well-being.

Additional factors considered include drainage density to avoid contamination of surface waters, and geological formations to mitigate hazards and leachate risks. Groundwater depth is a crucial parameter; landfill sites should be located in areas with deep groundwater to prevent aquifer contamination.

3.4.1. Criteria Exclusion

Certain criteria commonly used in other studies such as rainfall, groundwater depth, and soil characteristics were excluded due to the limited spatial variation within the study area. The homogeneity of rainfall and soil data rendered interpolation and reclassification ineffective, while the lack of detailed groundwater depth data prevented its inclusion.

3.4.2. Criteria Restrictions and Buffer Zones

GIS-based spatial analysis employed buffer zones around each criterion to define neutral zones based on suitability, environmental and health risks, and government regulations, including guidance from the Central Environment Authority (CEA). These buffer distances, reflecting recommended safe limits, are summarized in Table 1.

Table 1: Buffer zone for Criteria

No	Criteria	Buffer Zone	Experts' Suggestions
1	River	1km	(Javaheri et al., 2006) (Balasooriya et al., 2014)
2	Road	200m	(Javaheri et al., 2006) (Nas, 2010) (Mussa & Suryabhagavan, 2021)
3	Elevation	Exclude 1350-2100m	(Alkaradaghi et al., 2019)
4	Slope	$>20^0$	(Mussa & Suryabhagavan, 2021) (Rahmat et al., 2016)
5	Village and Towns	1km	(Nas, 2010) (Javaheri et al., 2006)
6	Religious and Public places	1km	(Dissanayake & Dissanayake, 2015)
7	Land use	Forest, Water, Urban	(Nas, 2010) (Mussa & Suryabhagavan, 2021)
8	Urban Centre	5km	(Alkaradaghi et al., 2019)

In this study, nine datasets were collected from various sources to serve as input parameters for the AHP (Analytic Hierarchy Process) and SAW (Simple Additive Weighting) modeling techniques. The primary data source was the United States Geological Survey (USGS) Earth Explorer, from which the Digital Elevation Model (DEM) for the study area was downloaded. Using spatial analysis tools-specifically slope and hydrology tools-slope and river maps were subsequently derived from the DEM.

Additional spatial data, including road networks, towns and villages, and public and religious places, were obtained from Open Street Map and processed for analysis. Furthermore, digital maps at a 1:50,000 scale (sheets 54 and 61) were acquired to develop the land use map. These sheets were merged to cover the study area, and the resulting land use map was converted into raster format for further spatial analysis. A detailed summary of the data sources and their attributes is provided in Table 2.

Table 2: Data Sources of the criteria

No	Criteria	Sources
1	River	DEM
2	Road	Open Street Map
3	Elevation	USGS Earth Explorer
4	Slope	DEM
5	Village and Towns	Open Street Map
6	Religious and Public places	Open Street Map
7	Land use	1:50 000 Digital Data

3.4.3. Sub criteria Rating Values

Table 3: Sub criteria values

	Criteria	Sub-Criteria	Rating Value	Reference
1	Rivers (Km)	0.5-1	0	(Mussa & Suryabhagavan, 2021)
		1.0-2.0	5	(Dissanayake, D.M.L, Dissanayake, 2015)
		2.0-3.0	3	
2	Slope	0-5	5	
		5.0-10.0	4	(Ersoy & Bulut, 2009)
		10.0-15.0	3	(Rahmat et al., 2016)
		15.0-20.0	2	
3	Roads (Km)	>1	0	(Mussa & Suryabhagavan, 2021)
		1.0-2.0	5	(Rahmat et al., 2016)
		2.0-3.0	3	
		>3	4	
4	Town & Villages (Km)	0-1	0	(Nas, 2010)
		1.0-2.0	2	(Alkaradaghi et al., 2019)
		>2	5	
5	Urban	<0.5	0	(Alkaradaghi et al., 2019)
		1-5-1.5	3	(Rahmat et al., 2016)
		>1500	5	
6	Land use	Waterbody	0	(Nas, 2010)
		Rock	5	(Rahmat et al., 2016)
		Scrub	4	(Alkaradaghi et al., 2019)
		Rubber	4	
		Paddy	3	
		Home garden	4	
		Tea	3	
7	Public and Religious sites (Km)	>1	0	(Dissanayake, Dissanayake, 2015)
		1.0-2.0	3	(Ersoy & Bulut, 2009)
		<3	5	
8	Elevation (Km)	1350-2100	1	
		1100-1350	2	(Alkaradaghi et al., 2019)
		920-1100	3	
		500-750	4	
		750-920	5	

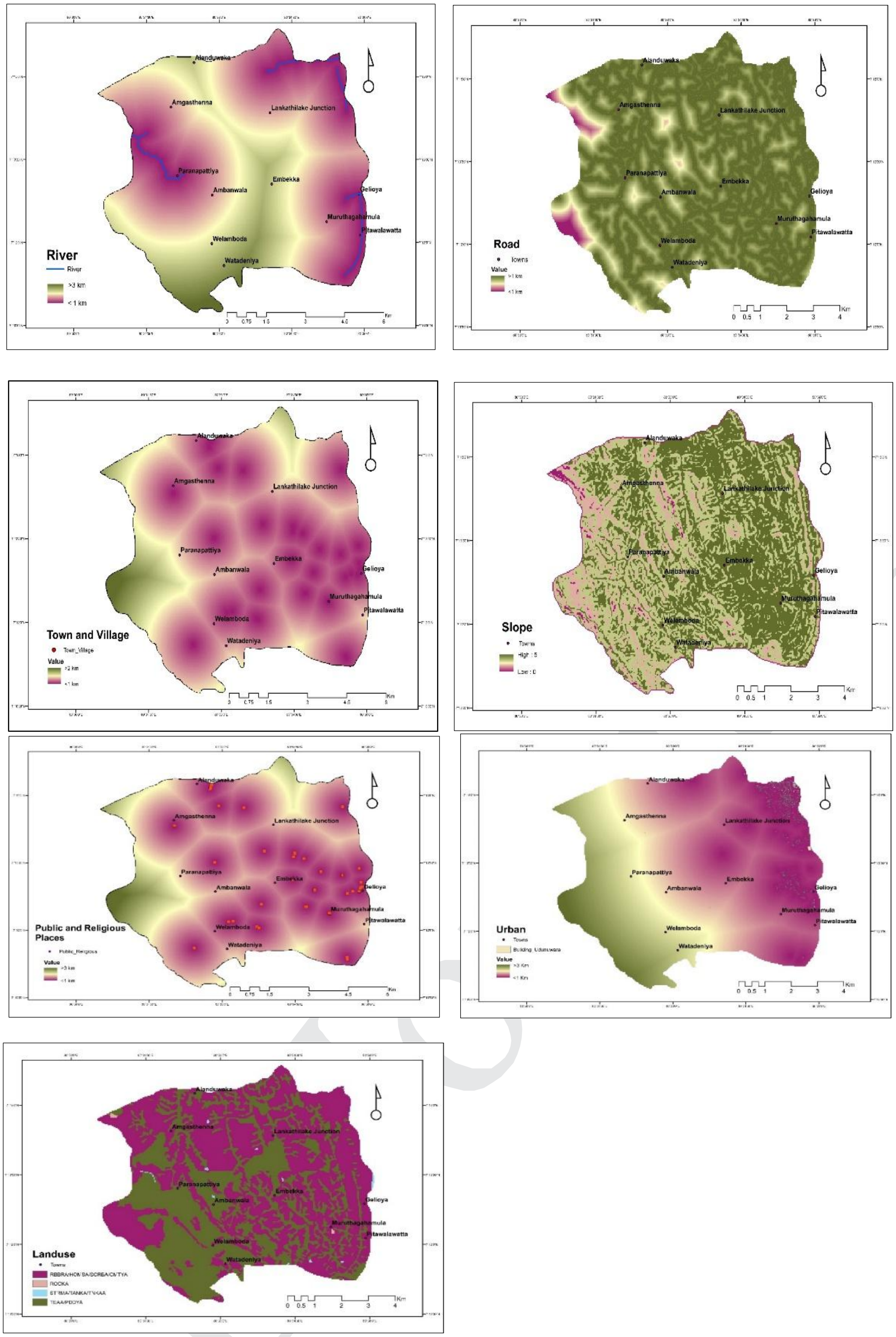

Figure 1: Suitability Maps for Criteria, By Author

3.5. Producing Land Suitability Map for Landfill Site

3.5.1. Analytical Hierarchy Process – AHP

The first step of the AHP is to create a hierarchical structure. In this study, there are two levels under the goal. The goal is set as "Selecting Suitable Landfill Site" and the first level is the criteria and the second level is the alternatives. The hierarchical structure for AHP modelling is presented in figure 5.

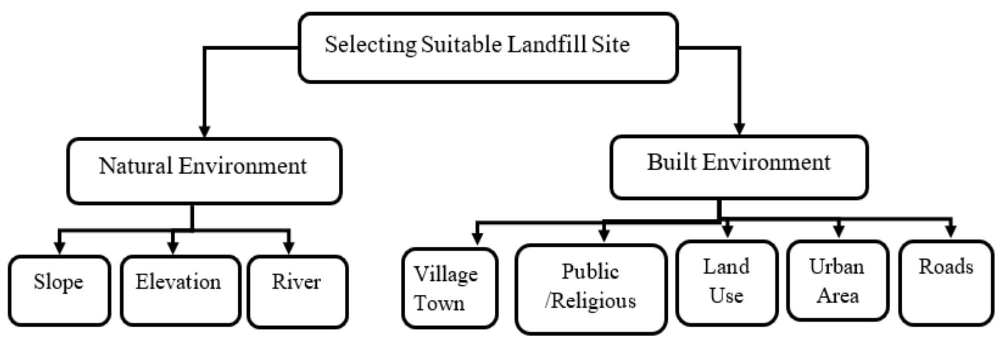

Figure 5: AHP Hierarchy Structure
Source: Author, (2021)

The next step is to create a pair-wise comparison matrix. This gives relative importance to the various attribute concerning the goal. The matrix is done by using a numerical scale of 1-9, where 1 is equally important, and 9 is extremely important. The scale for the pair-wise comparison is displayed in Table 4.

Table 4: Scale for Pair-wise Comparison

Numerical Value	Definition
1	Equal Importance
2	Equal to moderate Importance
3	Moderate Importance
4	Moderate to strong Importance
5	Strong Importance
6	Strong to very strong Importance
7	Very strong Importance
8	Very strong to extremely Importance
9	Extremely Importance

Source: (Alkaradaghi et al., 2019)

The pair-wise matrix for this study is constructed based on previous literature reviews and experts' ideas. Usually, the pair-wise matrix is written in Fraction format. The numerator represents the row element and the denominator will be representing the column element.

After completing the pair-wise matrix, it's obvious that the diagonal elements take the value of 1. The frictional value of pair-wise comparison Metrix will be converted into Decimals. The pair-wise matrix for the study is presented in Table 5.

Table 5: *Pair-Wise Comparison Matrix*

	A	B	C	D	E	F
A	1	3	5	1	6	3
B	0.33	1	3	0.33	4	1
C	0.2	0.33	1	0.2	2	0.33
D	1	3	5	1	6	3
E	0.17	0.25	0.5	0.17	1	0.25
F	0.33	1	3	0.33	4	1

A-River, **B**- Slope, **C**-Road, **D**- Village, **E**-Land use, **F**-Elevation

Source: Author, (2021)

The sum of each column is calculated to perform the normalization step. To normalize the pair-wise metrics all elements in the columns are divided by the sum value of the column. The eigenvectors for each row are calculated by, multiplying the value for each criterion in each column in the same row of the original pair-wise comparison matrix. The priority vector or AHP weight is determined by normalizing the eigenvalue to 1 (divided by their sum), using the following formula.

$$Pr_i = \frac{Eg_i}{\left(\sum_{i=1}^{n} Eg_i\right)}$$

Table 06: AHP Weights for the criteria

Criteria	River	Road	Slope	Town & Village	Land Use	Elevation
AHP	0.3177	0.1327	0.0588	0.3177	0.0404	0.1327
%	**31.7**	**13.2**	**5.8**	**31.7**	**4**	**13.27**

Source: Author, (2021)

$$\lambda_{max} = \sum_{j=1}^{n}\left[W_j \sum_{i=1}^{m} a_{ij}\right]$$

$$CI = \frac{(\lambda_{max} - n)}{(n-1)}$$

lambda (λ max) is obtained from the summation of values between each criterion of the priority vector and the sum of columns of the reciprocal matrix, as shown in the formula below;

Next is to calculate the Consistency Index (CI). It represents the equivalent of the mean deviation of each comparative element and the standard deviation of the evaluation error from the true ones (cite). It can be formulated through the formula below;

$$CR = \frac{CI}{RI}$$

λ max is the Principal Eigen Value; **n** is the number of factors

The consistency ratio (CR) is gained by dividing the consistency index value (CI) by the random index value. The Random Index (RI) for different sizes are presented in Table 6.3. CR can be obtained from the following formula;

The consistency ratio should be less than 0.1, to account as acceptable. In this study RI_6 = 1.24 and CI= 0.02374877; finally, CR= 0.019152234, which is less than 0.1; acceptable and the criteria weights or vector weights can be used as the final weights for the criteria.

Finally, to aggregate the criteria, the most commonly used decision-making rule Weighted Linear Combination- WLC was applied. WLC is based on the below formula,

$$\left(A_i = \sum_{j=1}^{n} W_j \times C_{ij}\right)$$

(where, Ai : is the suitability index, Wj : is the relative importance weight of the criterion, Cij: is the grading value (i) under criterion (j), and n: is the total number of criteria) in ArcGIS, to make the the WLC more efficient, using spatial analysis tool. "Map Algebra." The input for map algebra can be presented as follow;

S = ((F1 * 0.67) + (F2 * 0.06) + (F3 * 0.27) + (F4 * 0.06) + + (F5 * 0.06) + + (F6 * 0.06)) * cons_boolean

Table 7: The weights for the SAW

Criteria	River	Slope	Road	Village & Town	Land use	Elevation
Normalized weight	0.3298	0.1172	0.0590	0.3298	0.0468	0.1172
Weights %	32.9%	11.7%	5.9%	32.9%	4.6%	11.7%

,

Source: Author, (2021)

3.5.2. Simple Additive Weighting - SAW

$$S_{i} = D_{I} * W$$

Where - S_i -suitable index for area

D_I = selected data layer

W =important weight class

The SAW method is evaluated through the following formula.

The SAW weights were aggregated through the ArcGIS raster calculator using the above formula.

Comparing the weights of AHP and saw, it doesn't show huge differences, very tiny changes can be observed. The comparison between AHP and SAW weights is illustrated in Table 8.

Table 8: Criteria weights for AHP and SAW

	A	B	C	D	E	F	AHP	SAW
A	1	3	5	1	6	3	0.3177	0.3298
B	0.33	1	3	0.33	4	1	0.1327	0.1172
C	0.2	0.33	1	0.2	2	0.33	0.0588	0.0590
D	1	3	5	1	6	3	0.3177	0.3298
E	0.17	0.25	0.5	0.17	1	0.25	0.0404	0.0468
F	0.33	1	3	0.33	4	1	0.1327	0.1172

A-River, B- Slope, C-Road, D- Village, E- Land use, F-Elevation

4. Results

By completing the data aggregation, AHP and SAW land suitably maps can be produced separately.

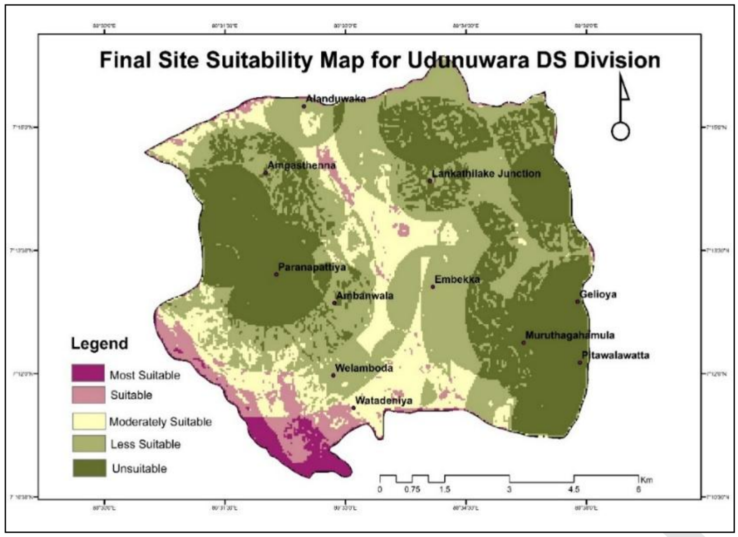

Figure 6: **Land Suitability Map with AHP and SAW**

By overlaying the AHP and SAW suitability maps, the most suitable landfill suitability map can be produced.

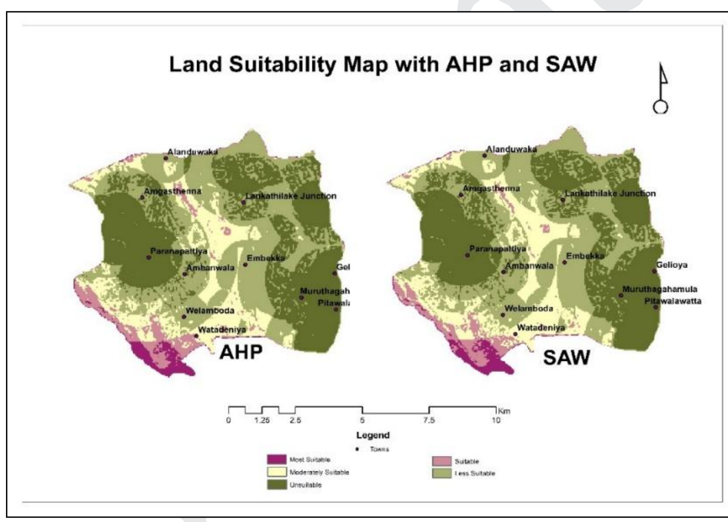

Figure 7: Final Land Suitability Map for Udunuwara DS Division

From the final land suitability map, 6% of the land within the study area is considered as most suitable for landfilling. 15%, 21%, and 28% of the lands are reflected as suitable, moderately suitable and less suitable respectively. A candidate site for landfilling has been spotted belonging to the most suitable region. The suitability of the land along with the criteria is presented below. The currently active dumpsite is also included in figure 8.

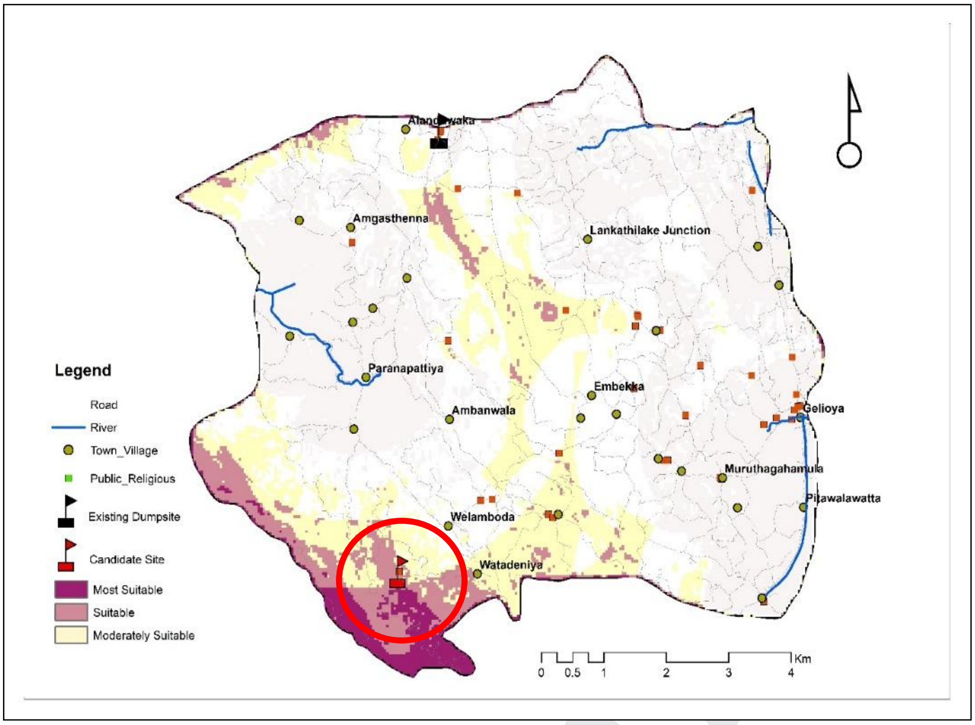

Figure 8: Site Suitability Map

As illustrated above, the currently active dumpsite in Kiriwaula belongs to the moderately suitable category. The suitability of the candidate site can be further explained in Table 9:

Table 9: Criteria Suitability for the Candidate Site

No	Criteria	Candidate Site Characteristic
1	River	3 km away from rivers
2	Road	100 m radius from the road
3	Slope	5-10^{0}-degree slope
4	Elevation	500-750 a.m.s.l
5	Urban	3 Km away from the Urban centres
6	Public / Religious	114m from a public place
7	Town / Village	1.23 km away from the villages and town
8	Land Use	Belongs to the tea plantation area

5. Conclusion

The results from the AHP and SAW methods provide complementary insights into the suitability of potential sanitary landfill sites within the Udunuwara Divisional Secretariat area. By integrating both methods through overlay analysis, the study identified spatial patterns of land suitability with enhanced reliability. The final suitability map revealed that only 6% of the study area is classified as most suitable for landfill development, highlighting the challenges in locating environmentally and socially acceptable sites in a relatively constrained landscape.

The gradation of suitability classes from most suitable to unsuitable provides valuable guidance for local authorities and planners. Notably, 15% of the land was classified as suitable, suggesting that additional areas could be considered if the most suitable sites are unavailable or inappropriate due to logistical or socio-political reasons. The moderately suitable and less suitable classes, accounting for 21% and 28% of the land respectively, indicate regions where landfill development could be possible but would require mitigation measures or further evaluation.

The candidate site identified within the most suitable class exhibits favorable characteristics aligned with the study's selection criteria. Its considerable distance from rivers (3 km) minimizes the risk of surface water contamination, an important factor given the potential for leachate migration. The proximity to roads (100 m radius) facilitates efficient waste transportation, reducing operational costs and emissions. The slope range (5°–100°) and elevation (500–750 m above mean sea level) are within acceptable limits, ensuring site stability and lowering flood risks. Furthermore, the site's location away from urban centers

(3 km) and villages (over 1 km) helps to reduce adverse effects on human health and local communities, including odors, noise, and aesthetic concerns. The land use classification as a tea plantation area suggests that the site is not currently used for dense residential or industrial purposes, which could simplify land acquisition and limit social conflicts. Interestingly, the currently active dumpsite in Kiriwaula is classified only as moderately suitable, reflecting the known environmental and health issues reported from this site. This reinforces the need to relocate or improve existing waste management facilities to safer and more sustainable locations.

Overall, the findings confirm the effectiveness of combining GIS-based spatial analysis with MCDA techniques (AHP and SAW) to support evidence-based decision-making in landfill site selection. However, it is essential to validate these findings through detailed field surveys, environmental impact assessments, and stakeholder consultations to address site-specific concerns and local knowledge.

6. Recommendations

Rapid urbanization in developing countries like Sri Lanka has intensified challenges in solid waste disposal, posing significant threats to the natural environment and public health. Improper methods such as uncontrolled open dumping have caused numerous problems, including slope failures, leachate contamination, and odor pollution. To mitigate these impacts, adopting sustainable waste disposal methods, particularly sanitary landfilling, is essential.

This study focused on identifying suitable landfill sites within the Udunuwara Divisional Secretariat using Geographic Information System (GIS) and Multi-Criteria Decision Making (MCDM) techniques specifically Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW). Seven key criteria, including land use, proximity to rivers, villages, towns, public and religious places, urban areas, slope, and elevation, were analyzed to produce a land suitability map. The study classified the area into five suitability zones, with approximately 30% of the land deemed unsuitable for landfill development.
The integration of GIS and MCDM offers valuable support for complex decision-making, enabling informed choices that balance waste management needs with environmental preservation and urban development. However, it is important to complement spatial analysis with physical, economic, and social considerations to ensure practical implementation.

A promising candidate site in Gonadikkawatta, recommended by the Urban Development Authority (UDA), was identified as the most suitable region. Although the Environmental

Impact Assessment (EIA) was approved by the Central Environment Authority (CEA), concerns regarding land stability raised by the Natural Building Resource Organization (NBRO) highlight the need for further investigations, including groundwater and soil studies. Besides Gonadikkawatta, other areas classified as suitable or moderately suitable could serve as landfill sites with appropriate engineering and management interventions.

Recommendations:

a. The local authorities should reconsider the proposal to develop the Gonadikkawatta site for landfill use. As this is government-owned land, collaboration between the local authority and NBRO to implement engineering stabilization measures could address land instability concerns. Successful development of this site could alleviate solid waste issues in Udunuwara, Kadugannava, and Gampola.

b. The government should consider acquiring private lands located within the most suitable, suitable, and moderately suitable zones to expand landfill site options.

c. The existing dumpsite at Kiriwaula should be upgraded to a controlled dumpsite by adopting improved waste management practices and necessary infrastructure to reduce environmental and health hazards.

d. Public awareness campaigns should encourage household composting of degradable waste to reduce the volume of waste requiring landfill disposal. Additionally, promoting the 3R practices Reduce, Reuse, Recycle—can minimize non-degradable waste generation, extend landfill lifespan, and reduce land requirements.

e. The Central Environment Authority should revise and simplify regulations concerning electronic waste (E-waste) management, ensuring rules are clear, practical, and enforceable to prevent environmental contamination.

f. By implementing these recommendations alongside the criteria identified in this study, Sri Lanka can move towards more sustainable and effective solid waste management, protecting both the environment and public health amid ongoing urban growth.

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