# A FOOD POLICY FRAMEWORK TO CKDU IN SRI LANKA

## Food, Water, and Health: A Systems Approach to CKDu

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**Swedish University of Agricultural Sciences, SLU**
**Department of Landscape Architecture, Planning and Management**
**Food and Landscape Programme.**
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**A food policy approach to CKDu in Sri Lanka:**
Implementing Food Policy to Address Chronic Kidney Disease of Unknown Etiology in Sri Lanka

Dinesha Rathnayake

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## ABSTRACT

Chronic Kidney Disease of Unknown Etiology (CKDu) has emerged as a major health issue in Sri Lanka, particularly among male agricultural workers in dry-zone districts. This study aimed to identify key environmental, occupational, and dietary risk factors contributing to the disease.

A mixed-methods approach was used, combining environmental sampling, community surveys, and stakeholder interviews. Water and soil samples collected from ten CKDu-endemic sites were analysed for heavy metals. Results indicated frequent exceedance of WHO safety thresholds for arsenic, cadmium, and lead, especially in Hingurakgoda, Padaviya, and Elahera. Water and Soil Quality Index scores further confirmed degraded environmental quality linked to intensive agricultural practices.

Occupational assessments revealed prolonged exposure to high temperatures and inadequate hydration among farming populations, consistent with clinical records linking heat stress to kidney damage. Dietary assessments showed heavy dependence on rice cultivated in contaminated soils and irrigated with polluted water, with limited dietary diversity contributing to chronic nephrotoxin exposure.

Together, these findings demonstrate that CKDu in the study regions is associated with combined risks from agrochemical contamination, occupational heat stress, and dietary vulnerability. The results highlight the need for integrated interventions that address environmental, occupational, and nutritional drivers of CKDu to safeguard farming communities in Sri Lanka.

**Keywords:**
Chronic Kidney Disease of Unknown Etiology (CKDu); Sri Lanka; agrochemical exposure; groundwater contamination; heavy metals (arsenic, cadmium, lead); heat stress; dietary exposure; soil pollution; Water Quality Index (WQI); occupational health; food safety; sustainable agriculture; food policy; Food Policy Councils (FPCs); NABC model; Rogers' Diffusion of Innovation; CEAT framework; High-Risk Cultivation Zones (HRCZs); climate-resilient farming; rural health; nephrotoxin mitigation; public health governance.

## PREFACE

The idea for this thesis was born out of a deep concern for the escalating health crisis caused by Chronic Kidney Disease of Unknown Etiology (CKDu) in Sri Lanka. Having witnessed firsthand the devastating impact of this condition on rural farming communities—especially in the North Central Province—I developed a strong personal and academic drive to investigate how food policy could be applied to mitigate the spread of this largely preventable disease. This research stems not only from compassion, but also from a critical awareness of the socio-environmental injustices faced by vulnerable populations exposed to contaminated resources, insufficient regulation, and limited access to public health safeguards.

My academic background has provided the interdisciplinary lens necessary to approach this complex issue. Prior to undertaking my Master's studies in Food and Landscape at the Swedish University of Agricultural Sciences, I earned a Bachelor's degree in Food Science and Technology and a Quality Management Diploma. These earlier academic experiences gave me foundational knowledge in agroecology, environmental health, and resource governance. Collectively, my education has enabled me to synthesize insights from agriculture, food & environmental science, and public policy, bringing them together under the broader subject of Food Studies to investigate CKDu as both a health crisis and a systemic food system failure.

The journey of completing this thesis has been shaped by a mix of determination, unexpected challenges, and meaningful collaborations. From designing and coordinating field surveys in the CKDu-affected areas of Anuradhapura and Polonnaruwa to the environmental sampling and subsequent analysis, every stage of this research demanded both scientific rigor and emotional resilience. The logistical constraints of managing fieldwork remotely, collaborating with local authorities, and responding to environmental unpredictability were considerable. However, each challenge became a milestone strengthening my resolve and deepening my engagement with the work.

Completing this thesis has been one of the most demanding yet rewarding experiences of my academic life. It has deepened my understanding of the intersections between environmental health, agriculture, and food policy, while reinforcing my belief in the power of community-driven, science-based solutions. I carry forward the hope that this work can contribute in some small way to improving the health and well-being of affected communities in Sri Lanka.

## ACKNOWLEDGEMENTS

I would like to extend my sincere gratitude to all those who supported me throughout the Master of Science in Food and Landscape at the Swedish University of Agricultural Sciences (SLU), culminating in this thesis. My deepest thanks go to the Faculty of Technology at the University of Sri Jayewardenepura for their institutional collaboration and to the dedicated student team who contributed to the success of the fieldwork. Their assistance with environmental sampling and survey administration in CKDu-affected regions provided essential support for the empirical component of this study.

I am equally grateful to Dr. Udayagee Kumarasinghe, Senior Lecturer at the Faculty of Technology, University of Sri Jayewardenepura, for her exceptional technical and logistical support. Her expertise in field research methodology, environmental sampling, and laboratory coordination was vital to the empirical strength of this study. Dr. Kumarasinghe's leadership in mobilizing student teams, overseeing sample collection, and advising on survey design and data analysis ensured that the field component of this research met rigorous scientific standards. Her ability to integrate practical problem-solving with academic insight greatly enhanced both the credibility and applicability of this research in real-world contexts.

I am also grateful to Ms. N.R.N. Silva, Principal Agriculture Scientist at the Horticultural Crops Research and Development Institute (HORDI), Department of Agriculture in Sri Lanka, for facilitating the laboratory testing of water and soil samples. Her collaboration ensured scientific accuracy and integrity in the environmental analyses.

Special thanks go to the individuals and communities in Anuradhapura and Polonnaruwa who generously participated in the surveys. Their openness and insights gave this work its social depth and contextual relevance.

I would also like to thank Love Sillow, Lecturer in the Food and Landscape program at SLU, for his helpful feedback and academic input throughout the program, which supported the clarity and coherence of this thesis.

I wish to express my sincere appreciation to my supervisor, Anna Peterson, Director of Studies for the Food and Landscape Master's Programme at SLU. Her teachings in Foodscapes 1 and 2 not only enriched my academic understanding but also helped me apply that knowledge meaningfully to the context of Sri Lanka's CKDu crisis. Her constructive critiques, strategic guidance, and unwavering encouragement were crucial to the success of this thesis. Her expertise in food systems, policy, and landscape planning greatly influenced the analytical direction of my research and supported my effort to integrate environmental health concerns into the broader landscape of food policy.

I am deeply thankful to my husband, Leonard de Lenarolle, whose support was instrumental throughout this journey. He not only funded the entire fieldwork and sample collection process but also used his network to connect me with key authorities and local contacts. His encouragement, resourcefulness, and belief in the value of this research were indispensable.
Finally, I would like to acknowledge the enthusiastic and hardworking students from the Food Science & Technology program at the University of Sri Jayewardenepura who contributed their time and energy to the fieldwork. Sagarika Ekanayake, Varnu Rathnayake, Sampath Jayawardena, Sameera Bodinayake, Kosala Ranaweera, Saptha Lenarolle, Gayan Kalinguarachchi, Sahan Dissanayake, Jayani Suchithra, and Dan Subhasinghe played a vital

role in the successful execution of the surveys and sample collection, often under challenging conditions. Their dedication was truly inspiring.

To everyone who contributed—academically, practically, or with encouragement—thank you for being part of this journey.

— Dinesha Rathnayake

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**Abbreviations**

| **Abbreviation** | **Full Name** |
|---|---|
| CKDU | Chronic Kidney Disease of Unknown Etiology |
| MRLs | Maximum Residue Limits |
| TAPE | Tool for Agroecology Performance Evaluation |
| FAO | World Health Organization |
| FPC | Food Policy Councils |
| NABC | Need, Approach, Benefit, Competition |
| WQI | Water Quality Index |
| PLI | Soil Pollution Load Index |
| GPS | Global Positioning System |
| GIS software | Geographic Information System |
| BOD | Biological Oxygen Demand |
| DO | Dissolved Oxygen |
| (TDS | Total Dissolved Solids |
| HRCZs | High-Risk Cultivation Zones |
| TEK | Incorporation of Traditional Ecological Knowledge |
| CRFS | City Region Food Systems |
| RO | Reverse osmosis |
| SLS | Sri Lankan Standard |

## .1. INTRODUCTION

Chronic Kidney Disease of Unknown Etiology (CKDu) has emerged as a major public health concern in rural agricultural regions of Sri Lanka. Unlike typical forms of chronic kidney disease (CKD), CKDu is not associated with common risk factors such as diabetes mellitus, hypertension, or glomerular nephritis (Jayatilake et al., 2013). Instead, it affects previously healthy individuals, primarily middle-aged male farmers, and progresses silently until the disease is advanced and irreversible, leading to end-stage renal disease and premature mortality (Wanigasuriya, 2012). CKDu has become the eighth leading cause of death in Sri Lanka, particularly affecting the North Central Province, causing not only a medical crisis but also socio-economic devastation in affected communities (Fernando et al., 2021).

***Figure 1.1: Landscape of rice paddy in Anurdhapura (Vanniarachchy, 2024)***

### 1.1 Sri Lankan Perspective on CKDu

The first documented cases of CKDu in Sri Lanka appeared in the early 1990s, with the North Central Province (notably Anuradhapura and Polonnaruwa) emerging as the primary endemic region. This temporal emergence coincided with a shift in agricultural practices driven by the Green Revolution, which encouraged the use of high-yield rice varieties, intensive irrigation, and increased reliance on agrochemicals such as synthetic fertilizers, pesticides, and particularly glyphosate-based herbicides (Chandrajith et al., 2011; Jayasumana et al., 2014). The proliferation of shallow wells and tube wells for both irrigation and drinking water introduced a new vector of chronic exposure to nephrotoxic contaminants like cadmium, arsenic, and fluoride found in groundwater (Nanayakkara et al., 2012; De Silva and Weerakoon, 2017). Geogenic contamination was further exacerbated by the region’s dry-zone climate, leading to a concentration of toxins in stagnant water sources during prolonged drought periods (Chandrajith et al., 2011).

As the disease advanced through other dry zone farming districts such as Medawachchiya, Kebithigollewa, Padaviya, and Rambewa in Anuradhapura, and Medirigiriya, Dimbulagala, and Elahera in Polonnaruwa, a pattern emerged correlating CKDu prevalence with regions of intensive rice cultivation and agrochemical dependency (Jayatilake et al., 2013). These areas share ecological and occupational similarities, suggesting a geographically and environmentally mediated distribution pattern linked to groundwater quality, climate, and farming practices (Wimalawansa, 2016a).

***Table1.1: Reported CKDu Cases in Selected Divisions of Sri Lanka 2013 & 2017***

| District | Division | Reported Cases | Year of Data |
|---|---|---|---|
| Anuradhapura | Medawachchiya | 3,194 | 2013[1] |
| Anuradhapura | Padaviya | 2,653 | 2013[1] |
| Anuradhapura | Kebithigollewa | 1,052 | 2013[1] |
| Anuradhapura | Rambewa | 800 | 2013[1] |
| Anuradhapura | Horowpathana | 473 | 2013[1] |
| Anuradhapura | Kahatagasdigiliya | 541 | 2013[1] |
| Polonnaruwa | Medirigiriya | 1,114 | 2013[1] |
| Polonnaruwa | Dimbulagala | 702 | 2013[1] |
| Polonnaruwa | Elahera | 827 | 2017[2] |
| Polonnaruwa | Hingurakgoda | 669 | 2017[2] |

**Footnotes:**
**[1]Data from *Sunday Observer* (2014, April 13). *CKDu—The silent killer in the dry zone*.**
**[2]Data from *Remediation Australasia* (2017). *Unravelling the link between kidney disease and environmental contaminants in North Central Sri Lanka*.**

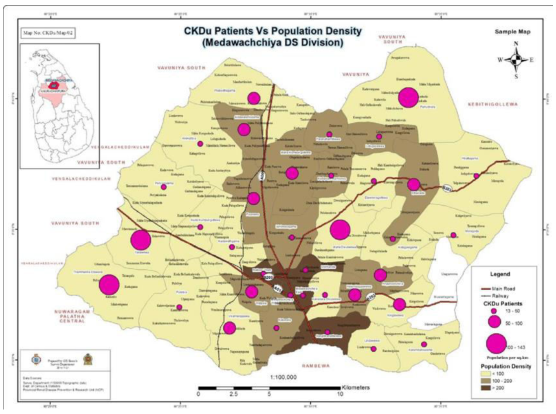


***Figure 1.2: Geographical distribution of CKDu cases versus population density in Madawachchiya DS Division, Anuradhapura District, Sri Lanka. Source: Bandara et al. (2019)***

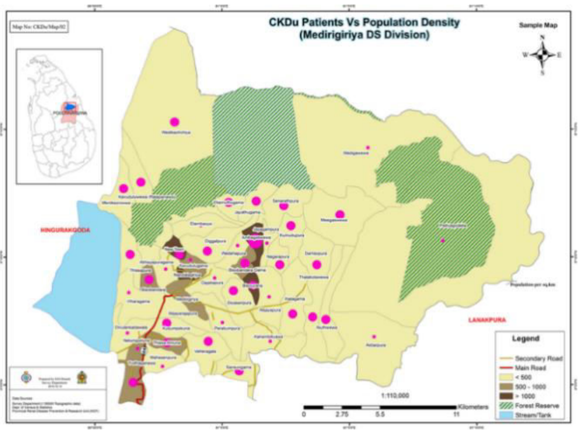


***Figure 1.3 : Geographical distribution of CKDu cases versus population density in Madirigiriya DS Division, Polonnaruwa District, Sri Lanka. Source: Bandara et al. (2019)***

Despite the significant public health burden posed by CKDu and its apparent links to agricultural and environmental exposures, Sri Lanka's existing food and agricultural policies have largely failed to address the disease in a comprehensive or integrated manner. Current food policy frameworks prioritize productivity, food security, and economic efficiency, with limited regulatory oversight on pesticide residues, groundwater safety, or agroecological sustainability in CKDu-endemic regions. The absence of localized, health-integrated food governance mechanisms has created a critical policy vacuum. As a result, there is an urgent need for a context-specific food policy that bridges the disconnect between agriculture, water quality, and rural public health to mitigate CKDu in affected districts such as Anuradhapura and Polonnaruwa.

### 1.2 Global Perspectives on CKDu

While Sri Lanka remains a prominent hotspot, CKDu-like syndromes have emerged globally in other agricultural regions with similar environmental and occupational stressors. In Central America, particularly in El Salvador and Nicaragua, Mesoamerican Nephropathy has affected sugarcane workers exposed to extreme heat and dehydration, compounded by agrochemical exposure and poor water quality (Peraza et al., 2012; Wesseling et al., 2013a). In Mexico, regions such as Tierra Blanca exhibit elevated CKDu incidence linked to pesticide exposure and chronic dehydration among field labourers (García-Trabanino et al., 2015).

In India, particularly in Andhra Pradesh and Odisha, clusters of CKDu have been identified in farming populations where contaminated groundwater and pesticide residues have been implicated (Reddy and Gunasekar, 2013). Similarly, in Europe, studies from Spain and Italy suggest a potential link between chronic pesticide exposure and renal dysfunction among agricultural workers, although CKDu remains underdiagnosed due to limited surveillance and misattribution to traditional CKD causes (García-García et al., 2014).

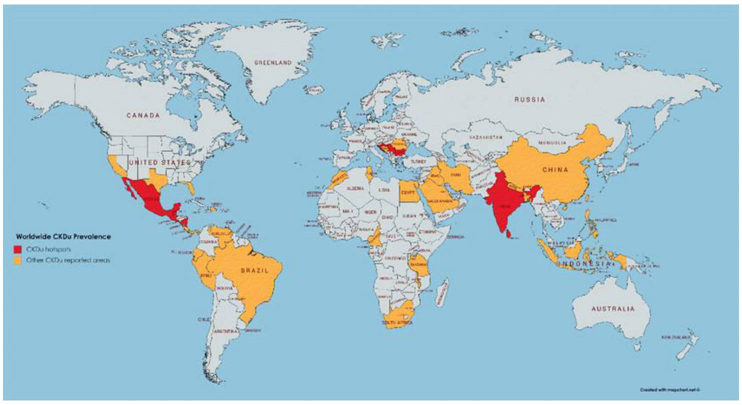


***Figure 1.4: Worldwide CKDu prevalence. Red colour for CKDu hot spots and orange colour for other CKDu reported countries (Priyadarshani et al., 2022, Figure 1)***

Globally, CKDu appears to follow a pattern of emergence in low-resource agricultural communities, particularly in hot climates, where water contamination, occupational dehydration, and agrochemical exposure converge as key risk factors (WHO, 2016; Weaver et al., 2015).

### 1.3 Rationale for the Study

The multifactorial Etiology of CKDu necessitates a holistic policy-oriented research approach. This study aims to examine environmental exposures—especially agrochemical residues and water contamination—and their associations with CKDu prevalence in Sri Lanka. By analysing spatial correlations between land-use practices and groundwater toxicity in affected regions, the research seeks to inform evidence-based food and public health policy interventions. The goal is to mitigate CKDu incidence and improve the long-term well-being of rural farming communities.

### 1.4 Research Questions

The study aims to answer the following research questions
Main Research Question:

> **How can a food policy be developed and implemented to effectively mitigate Chronic Kidney Disease of Unknown Etiology (CKDu) in Sri Lanka's Anuradhapura and Polonnaruwa districts?**

Sub-questions:

1. How can the enforcement of Maximum Residue Limits (MRLs) for agrochemicals in water, and effectively reduce nephrotoxic exposure pathways contributing to CKDu in endemic regions of Sri Lanka?
2. What is the potential of adopting low-input, circular agroecological farming systems guided by the FAO's Tool for Agroecology Performance Evaluation (TAPE) to minimize environmental toxicant load and enhance ecosystem resilience in CKDu-affected agricultural landscapes?
3. How can multi-scalar governance frameworks, integrating district-level Food Policy Councils (FPCs) and national regulatory bodies, improve participatory decision making to advance food safety, environmental health, and CKDu mitigation in Sri Lanka?

These research questions will be answered to develop targeted strategies to reduce CKDu incidence and promote the health and well-being of Sri Lanka's farming communities.

### 1.5 Application of Theoretical Frameworks and Practical Knowledge in Developing a Food Policy framework for CKDu in Sri Lanka

Addressing CKDu in Sri Lanka demands a transdisciplinary policy approach that integrates public health, agriculture, and environmental governance. Drawing on academic frameworks learned during the MSc in Food and Landscape program, this study applied several practical and theoretical tools.

The **Krinova Innovation Hub model** was adapted to facilitate co-creation of sustainable farming interventions with farmers, agronomists, public health professionals, and local policymakers. Participatory innovation workshops were proposed to promote alternatives to hazardous agrochemical usage and identify community-driven solutions.

**Rogers' Diffusion of Innovation Theory** was utilized to assess the uptake of sustainable farming practices such as organic agriculture and integrated pest management in affected regions. Early adopters within rural communities can act as agents of change, promoting adoption of low-risk practices to reduce exposure to environmental nephrotoxins (Rogers, 2003).

The **NABC model (Need, Approach, Benefit, Competition)** structured the strategic formulation of a food policy. The "Need" is based on epidemiological data highlighting CKDu's severity; the "Approach" proposes policy innovations such as groundwater testing, agrochemical regulation, and promotion of sustainable farming; "Benefits" include improved public health and food security; while "Competition" addresses resistance from agrochemical interests and the socioeconomic dependency on chemical-intensive farming.

**A Tool for Agroecology Performance Evaluation (TAPE)** was applied using its 'Performance on the Ground' indicators related to environmental sustainability, with a focus on chemical input use and contamination risks. Data on pesticide and fertilizer practices, together with laboratory analysis of water and soil samples, were evaluated against these indicators to profile chemical risks in the study sites. For contextual relevance, previous studies in Hingurakgoda (De Silva & Weerakoon, 2017) have also confirmed the presence of nephrotoxic substances in groundwater, underlining the importance of assessing chemical exposure through tools such as TAPE.

**Food Policy Council principles** were adapted to create multi-stakeholder governance structures capable of bridging local knowledge and scientific research. A regional council was proposed for Anuradhapura and Polonnaruwa to regulate agrochemical usage, promote clean water access, and facilitate agroecological transition.

Policies from the **Food and Agriculture Organization (FAO)** emphasizing food safety, pesticide regulation, and sustainable agriculture were incorporated to ensure that local policy aligns with international standards, especially given the detection of pesticide residues in rice and vegetables from CKDu-endemic areas (FAO, 2020).

Planning knowledge gained during the master's program was translated into design concepts for landscape-level interventions in CKDu hotspots such as Rambewa. This included advocating agroforestry systems, organic transition strategies, and protected well construction to ensure access to uncontaminated water.

## 2. LITERATURE REVIEW

A comprehensive understanding of the existing literature on Chronic Kidney Disease of Unknown Etiology (CKDu) is essential to underpin this research's rationale and its food policy-oriented framework. This review covers the prevalence and risk factors of CKDu, the role of agrochemical practices, dietary nephrotoxins, global and local policy responses, and identifies critical knowledge gaps. Emphasis is placed on studies from Sri Lanka, India, Central America, and other affected regions to contextualize CKDu within a global public health and environmental health paradigm.

### 2.1 CKDu Prevalence and Risk Factors

CKDu has become a major health crisis in agricultural regions where traditional risk factors such as diabetes and hypertension are absent. In Sri Lanka, particularly in the North Central Province (NCP), the disease has affected over 70,000 individuals, with most cases reported from Anuradhapura and Polonnaruwa districts (Jayatilake et al., 2013; WHO, 2016). The disease typically manifests late, is often asymptomatic in early stages, and results in chronic renal failure, leading to death if untreated (Senanayake et al., 2021).

This trend is not unique to Sri Lanka. In Central America, notably in Nicaragua and El Salvador, a similar epidemic known as Mesoamerican Nephropathy (MeN) has emerged. Agricultural workers, particularly sugarcane harvesters, exhibit extremely high rates of CKDu up to 60% in some regions with repeated heat stress, dehydration, and agrochemical exposure implicated as key drivers (Peraza et al., 2012; Wesseling et al., 2013b). Likewise, in the Uddanam region of Andhra Pradesh, India, CKDu prevalence is alarmingly high, with studies suggesting links to water contamination, pesticide use, and low healthcare access (Ravindra et al., 2017; Reddy et al., 2019).

These geographically distinct but demographically similar outbreaks reinforce the hypothesis that CKDu arises from shared environmental and occupational stressors, particularly in rural, agricultural settings. Commonalities include intensive agrochemical use, poor protective regulation, contaminated groundwater, extreme heat, and socio-economic marginalization (Jha et al., 2013; Fischer et al., 2020). These correlations are foundational to this study's proposal to integrate environmental health concerns into national food policy for CKDu mitigation.

### 2.2 Agrochemical Use in Sri Lanka

Sri Lanka's agricultural sector has witnessed a sharp increase in agrochemical use since the liberalization of its economy in the late 1970s. The proliferation of glyphosate-based herbicides, phosphate fertilizers, and other synthetic inputs without adequate regulation has been widely implicated in environmental contamination (Chandrajith et al., 2011; Bandara et al., 2010). Elevated levels of cadmium and arsenic have been detected in soil, water, and rice grains from endemic zones, suggesting long-term environmental accumulation of nephrotoxic agents (Jayasumana et al., 2015a; De Silva & Weerakoon, 2017).

These concerns are echoed globally. In Mexico, farmers exposed to pesticides like paraquat, glyphosate, and chlorpyrifos also show higher incidence of kidney dysfunction (Orantes-Navarro et al., 2016). Similarly, research from India shows the correlation between intensive pesticide use and kidney health deterioration in Punjab and Andhra Pradesh (Reddy et al., 2019). In contrast, the European Union applies the REACH regulatory framework and

Maximum Residue Limits (MRLs) to monitor and limit agrochemical residues in food and the environment (EFSA, 2012).
These policy disparities demonstrate that weak regulatory infrastructure significantly increases public exposure to nephrotoxins, supporting the urgent need for food safety reforms in Sri Lanka.

### 2.3 Dietary Exposure to Contaminants

Dietary intake is a key pathway of nephrotoxic exposure in CKDu-endemic regions. Rice, the dietary staple in Sri Lanka, is cultivated in contaminated fields and irrigated with water containing cadmium, arsenic, and glyphosate (Bandara et al., 2010; Jayasumana et al., 2015a). The bioaccumulation of these substances in staple foods can lead to chronic kidney damage over time.
Evidence from Sri Lanka shows that rice samples from affected regions exceed safe limits for cadmium, posing long-term health risks (Wanigasuriya et al., 2011). Similarly, a study by the European Food Safety Authority (EFSA, 2012) links long-term dietary cadmium exposure to decreased renal function even at low doses. In India, food crops irrigated with contaminated water have similarly been found to concentrate nephrotoxins, raising concerns about chronic exposure (Ravindra et al., 2017).
In Central America, maize and beans dietary staples have been shown to contain residues of agrochemicals linked with CKDu (Wesseling et al., 2014). These findings underscore the importance of food safety monitoring and validate this study's objective of incorporating crop screening and dietary regulation within CKDu prevention strategies.

### 2.4 Existing Policies and Knowledge Gaps

Sri Lanka's national response to CKDu has thus far prioritized medical management—such as dialysis centres and public awareness programs—over upstream preventive measures (Ministry of Health, 2019). However, there is minimal policy attention on regulating agrochemicals, enforcing MRLs, or monitoring nephrotoxins in food and water (Jayasumana et al., 2015b).
European nations have responded to environmental health risks through strict enforcement of agrochemical usage, food quality control, and occupational health standards (ECHA, 2020). In Latin America, nascent policy efforts are emerging to improve labor safety and reduce heat exposure in agriculture (ILO, 2019). Yet, even in these countries, CKDu remains under-recognized in public health agendas.
Critically, there is a dearth of interdisciplinary research that integrates food systems, environmental science, and public health in CKDu-endemic regions (Fischer et al., 2020). This gap highlights the need for a new food policy paradigm that proactively addresses environmental and dietary risks.

### 2.5 Summary of Relevance

This literature review reveals a clear pattern: CKDu emerges predominantly in rural, agrarian regions where environmental and occupational health risks intersect with poor food safety oversight. The reviewed evidence highlights:

- A shared global pattern of CKDu in underserved agricultural communities.
- A strong correlation between agrochemical exposure and renal dysfunction.
- Dietary nephrotoxin exposure through staple foods like rice.

- Inadequate policy frameworks in Sri Lanka and globally.

Together, these insights support the development of a comprehensive, evidence-based food policy intervention that integrates health, agriculture, and environmental management the central goal of this thesis.

## 3. METHODOLOGY

### 3.1 Mixed-Methods Research Design

This study adopted a mixed-methods research design, integrating both quantitative and qualitative approaches to investigate the relationship between agrochemical exposure and the prevalence of Chronic Kidney Disease of Unknown Etiology (CKDu) in Sri Lanka. The mixed-methods approach enables the triangulation of data to provide a holistic and robust understanding of complex socio-environmental health problems (Creswell & Plano Clark, 2018; Johnson et al., 2007).

As the principal researcher based in Sweden, I assumed the role of project leader and coordinated all aspects of the fieldwork conducted in Sri Lanka. This included overseeing the design and implementation of household and stakeholder surveys, supervising the collection of water and soil samples, and ensuring the integrity of laboratory testing procedures. Although geographically distant, I maintained continuous engagement through online platforms, providing real-time oversight and guidance to local research assistants. In several instances, I directly participated in survey administration to ensure methodological consistency and data quality. All research activities were executed under my direct supervision to uphold scientific rigor and alignment with the study objectives.

#### 3.1.1 Rationale for a Mixed-Methods Approach

CKDu is widely recognized as a multifactorial disease, influenced by a convergence of environmental, occupational, behavioural, and socio-political factors (Jayatilake et al., 2013; Wimalawansa, 2016b). As such, a singular methodological lens would be insufficient to uncover the full spectrum of its determinants.

Quantitative methods offer objective assessments, such as the presence and concentrations of heavy metals in soil and water, while qualitative methods provide insights into community perceptions, agricultural practices, and risk behaviours. This duality addresses the limitations of single-strand methodologies: purely quantitative approaches may overlook socio-cultural dynamics, while qualitative methods lack the empirical rigor required to establish environmental health risks (Teddlie & Tashakkori, 2009; O'Cathain et al., 2010).

Therefore, the integration of both methods is essential to explore:

- The extent of environmental contamination, and
- The lived experiences and perceptions of affected communities regarding CKDu.

This comprehensive approach has been successfully applied in similar public health investigations in India (Reddy et al., 2020), Central America (Ramírez-Rubio et al., 2016), and Egypt (El Minshawy, 2011), where environmental exposures and local practices converge to influence kidney disease risk.

#### 3.1.2 Implementation of the Mixed-Methods Approach for Data Collection and Analysis

The study followed a **convergent parallel mixed-methods design**, where qualitative and quantitative data were collected simultaneously but analyzed separately. The results were later merged during interpretation to identify convergences and discrepancies. This allowed for the triangulation of findings, combining environmental data (e.g., soil and water analysis) with social perspectives (e.g., resident behaviours and perceptions) (Creswell & Plano Clark, 2018).

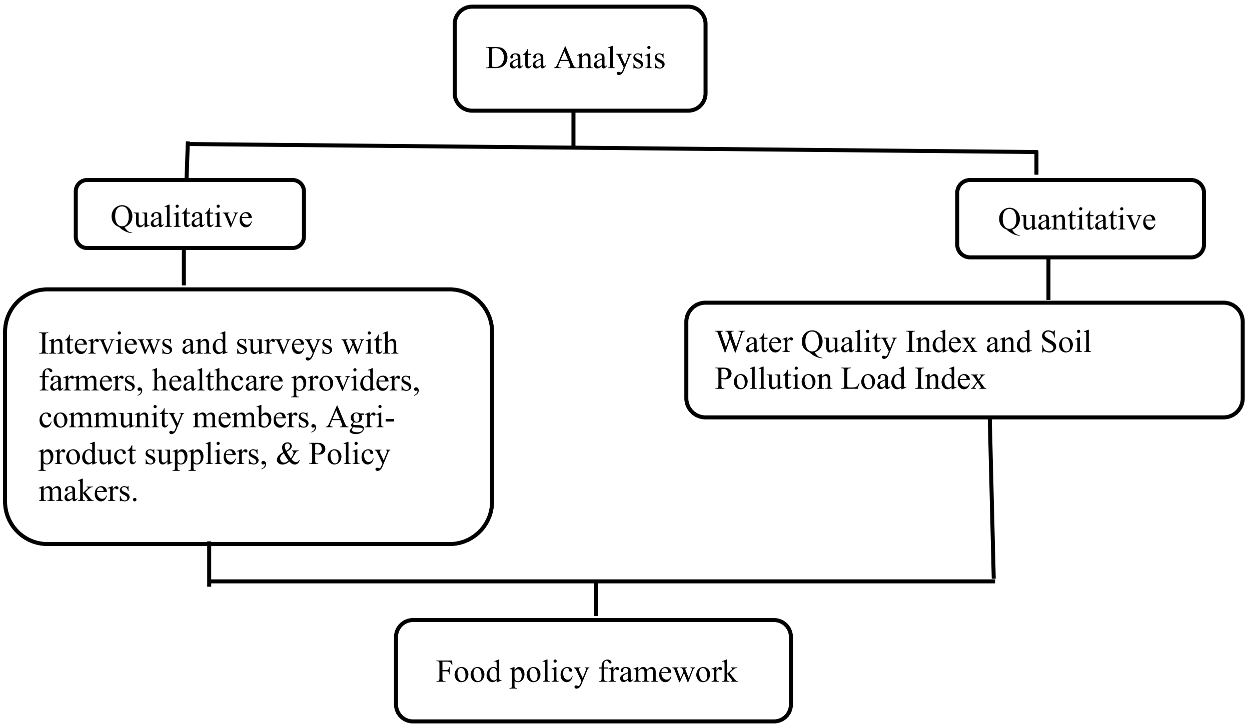


***Figure 3.1: Overview of Data Analysis Framework: Quantitative and Qualitative Approaches.***

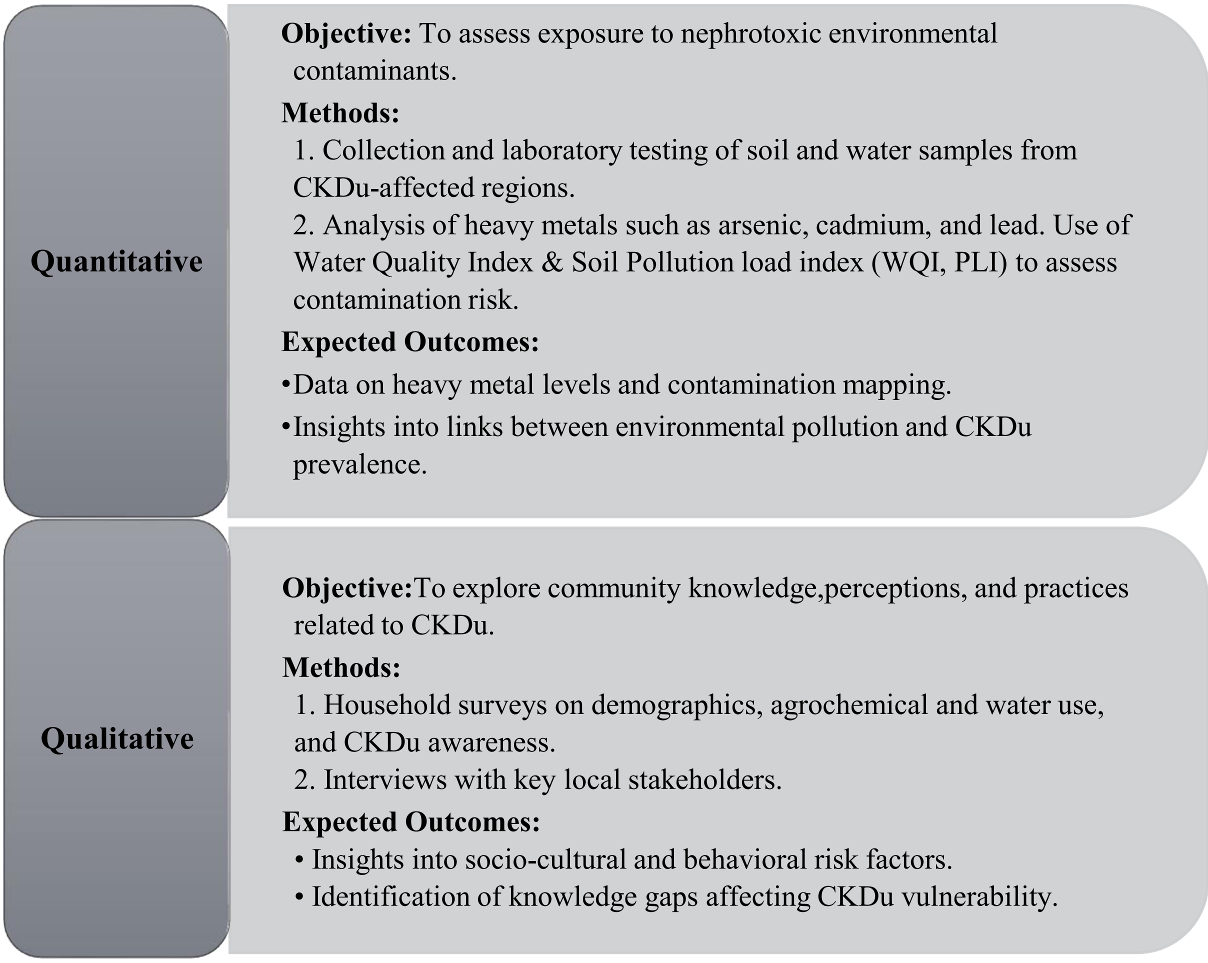


***Figure 3.2: Mixed-Methods Research Framework for Investigating CKDu Determinants.***

### 3.1.3 Research Coordination and Collaborative Execution

The overall study design, including the development of data collection instruments, environmental sampling strategies, and analytical procedures, was formulated in Sweden. Due to the geographical constraints, field implementation was carried out in collaboration with a team of undergraduate research assistants from the University of Sri Jayewardenepura, Sri Lanka. This team was responsible for administering household and stakeholder surveys and collecting soil and water samples from identified CKDu hotspot regions.

The collected environmental samples were subsequently transported to the Horticultural Crops Research and Development Institute (HORDI) under the Department of Agriculture, Sri Lanka, where laboratory analyses were conducted under the supervision of a Principal Agricultural Scientist. Throughout the data collection and laboratory phases, continuous oversight was maintained through digital communication platforms, enabling real-time guidance, troubleshooting, and quality assurance. In selected instances, virtual participation was undertaken during survey sessions to support methodological consistency.

All raw data obtained from field surveys and laboratory testing were securely transferred for analysis. Quantitative, thematic, and spatial analyses were conducted by the lead researcher to ensure the coherence, reliability, and scientific integrity of the study. This remotely coordinated yet collaborative approach facilitated the integration of local expertise with internationally guided research standards.

### 3.1.4 Relevance to Research Goals

The overarching aim of this research is to bridge empirical environmental science with community-informed social data to support the development of effective policy interventions. The mixed-methods approach serves this purpose by:

- Facilitating triangulation of data to increase the validity and reliability of findings (Denzin, 2012).
- Allowing for integration of diverse perspectives—quantitative data on contamination, and qualitative insights into human behavior and systemic practices (Bryman, 2006).
- Capturing hidden or emergent variables, such as traditional farming beliefs or mistrust in governmental advice, which may influence risk exposure (McKim, 2017).
- Informing evidence-based food and water policy recommendations that are both environmentally sound and socially relevant (Wickramage et al., 2021).

### 3.1.5 Contribution to Problem-Solving

This integrated approach allows the study to:

***Table 3.1: Integrated Focus Areas, Methods, and Expected Outcomes for CKDu Risk Mitigation***

| Focus Area | Methods/Tools | Expected Outcomes |
|---|---|---|
| **Environmental Hotspots** | GIS Mapping, Heavy Metal Testing | Identification of contamination "hot zones" |
| **Human Activity & Exposure Pathways** | Behavioural Surveys, Observations | Understanding exposure routes |

| | | |
|---|---|---|
| **Knowledge Gaps & Misperceptions** | Focus Groups, Interviews | Targeted education & awareness |
| **Policy & Community Interventions** | Stakeholder Workshops, Policy Analysis | Evidence-based regulations and programs |

In essence, the mixed-methods framework transcends the limitations of single-dimensional studies, asking not only **"What is occurring?"** but also **"Why is it occurring, and what can be done to change it?"**

### 3.2 Study Area and Population

The study was conducted across ten identified CKDu hotspot areas within the Anuradhapura and Polonnaruwa districts of Sri Lanka. These regions were selected due to their documented high prevalence of CKDu and their heavy reliance on agriculture, particularly paddy farming, which involves the extensive use of agrochemicals (Jayatilake et al., 2013; WHO, 2016). The selected locations are:

**Anuradhapura District:**

- Medawachchiya
- Kebithigollewa
- Padaviya
- Rambeva
- Horowpathana
- Kahatagasdigiliya

**Polonnaruwa District:**

- Medirigiriya
- Dimbulagala
- Elahera
- Hingurakgoda

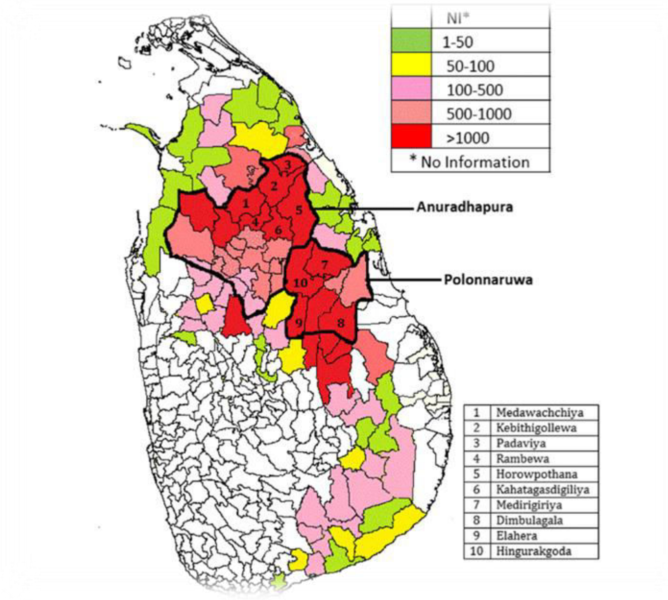


***Figure 3.3: CKDu hotspot in Sri Lanka (Ranasinghe et al., 2019, Figure 2)***

The population in these regions predominantly consists of smallholder farmers with frequent exposure to agrochemicals through occupational activities and domestic water sources, posing a potential nephrotoxic risk (Jayasumana et al., 2014).

### 3.3 Sample Locations and Mapping

To ensure spatial diversity and representativeness, 100 environmental samples were collected across the ten CKDu-affected sites, comprising 5 water and 5 soil samples from each area. This sampling framework was designed to enable the dual evaluation of environmental contamination through both **Water Quality Index (WQI)** and **Soil Pollution Load Index (PLI)** methodologies.

Due to field constraints, the sampling was carried out under the remote supervision of the principal investigator and direct oversight of Dr. Udayagee Kumarasinghe (University of Sri Jayewardenepura), with technical execution by trained undergraduate students from the Department of Food Science and Technology. The laboratory analyses were carried out at the **Horticultural Crops Research and Development Institute (HCRDI), Department of Agriculture**, following international quality assurance protocols (APHA, 2017; ISO/IEC 17025:2017).

**Sampling Points and Selection Criteria**

Soil and water sampling locations were strategically selected to reflect potential exposure pathways and human–environment interactions. The sources included community wells, which serve as the primary means of obtaining drinking and domestic water; areas surrounding local schools, representing sensitive populations; paddy fields, known for intensive agrochemical application; irrigation reservoirs, which are used for both agricultural and domestic purposes; and village peripheries, which represent mixed-use exposure zones. This approach supports a comprehensive understanding of environmental risk factors associated with CKDu

### 3.3.1 Geographic Mapping and Visualization

All sampling points were geo-referenced using GPS technology. These locations were then visualized using GIS software to produce individual maps for each CKDu hotspot area. The maps were overlaid with satellite imagery and include photographic documentation to ensure spatial transparency and field validity (ESRI, 2022).

- **Blue dots:** Water sampling sites
- **Brown dots:** Soil sampling sites


*Figure 3.4: Sample collection points of Medawachchiya (Source: Google Maps, 2025)*


*Figure 3.5: Sample collection points of Kebithigollawa (Source: Google Maps, 2025)*


*Figure 3.6: Sample collection points of Rambewa (Source: Google Maps, 2025)*

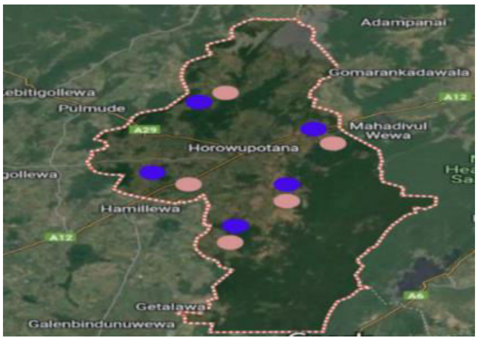


*Figure 3.7: Sample collection points of Horowpathana (Source: Google Maps, 2025)*

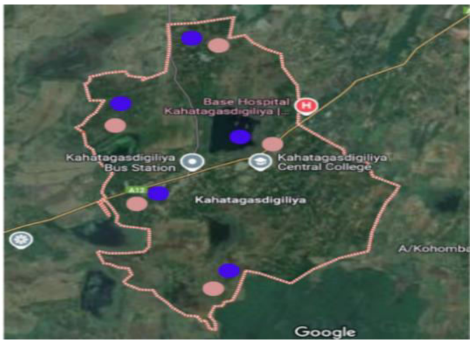


*Figure 3.8: Sample collection points of Kahatagasdigiliya (Source: Google Maps, 2025)*

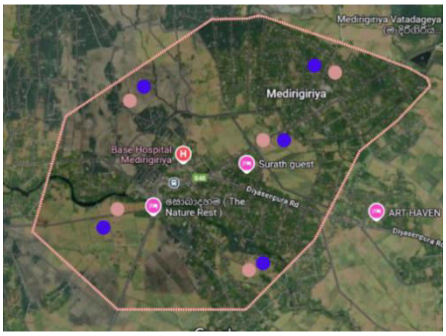


*Figure 3.9: Sample collection points of Medirigiriya (Source: Google Maps, 2025)*

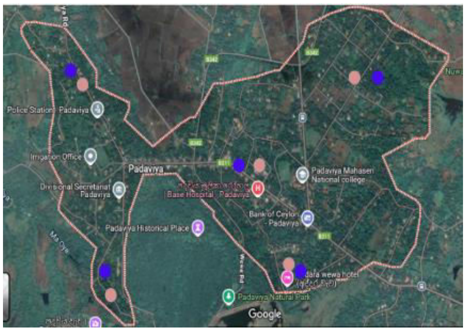


*Figure 3.10: Sample collection points of Padaviya (Source: Google Maps, 2025)*


*Figure 3.11: Sample collection points of Higurakgoda (Source: Google Maps, 2025)*


*Figure 3.12: Sample collection points of Elahera (Source: Google Maps, 2025)*

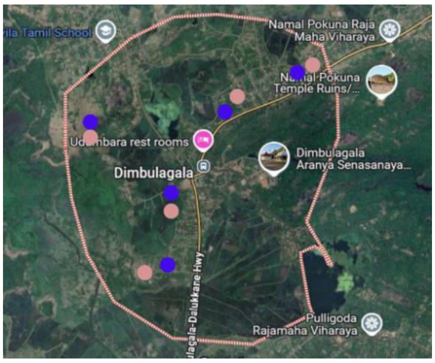


*Figure 3.13: Sample collection points of Dimbulagala (Source: Google Maps, 2025)*

### 3.3.2 Survey and Interview Design

To complement the environmental data and provide a multidimensional perspective on the social and behavioural determinants of CKDu, a qualitative component was integrated into the study using structured household surveys and semi-structured key informant interviews. These tools were designed to explore community knowledge, risk perceptions, and behavioural patterns that may contribute to CKDu vulnerability in rural Sri Lanka.

A total of 100 structured household surveys were conducted across the ten identified CKDu hotspot areas. The survey instrument was developed based on existing literature and adapted to the local context through pre-testing and expert consultation. The questionnaire was administered in the local language (Sinhala) and covered the following domains:

- **Demographic information**: age, gender, education, occupation, household size
- **Water consumption habits**: source and treatment of drinking water, frequency of use
- **Agricultural practices**: type of crops cultivated, frequency and types of agrochemicals used, protective measures adopted during application
- **Knowledge and awareness of CKDu**: sources of information, perceived risk factors, symptoms, and prevention strategies.

The structured nature of the survey ensured consistency across responses while allowing for the quantification of key variables. Previous studies have emphasized the importance of understanding household behaviors and water use patterns in identifying risk pathways for CKDu ( Jayasumana et al., 2014).

To complement the policy and document analysis, structured surveys were conducted from 1st to 28th February 2025 across CKDu-affected regions of Sri Lanka. The purpose was to gather multi-perspective insights into awareness, behaviours, and institutional responses to CKDu from key stakeholder groups.

***Table 3.2 : Stakeholder Engagement and Thematic Insights in CKDu-Affected Regions***

| Participant Group | Number of Participants | Locations | Focus of Survey/Interview | Key Insights Gained |
|---|---|---|---|---|
| **Smallholder Farmers** | 50 | 5 from every CKDu hotspot | Awareness of CKDu, agrochemical use and health risk knowledge | Exposure behaviours, knowledge gaps |
| **Agrochemical Product Suppliers** | 15 | Medawachchiya Dimbulagala, Elahara, Padaviya Anuradhapura Polonnaruwa | Fertilizer/pesticide sales, regulatory awareness, and enforcement challenges | Role in promoting safe practices |
| **Local Public Health Officials** | 15 | High-prevalence areas | Diagnosing, treating, and community education on CKDu | Clinical perspective, public health communication |

| | | | | |
|---|---|---|---|---|
| **Community Members** | 10 | Medawachchiya Padaviya, Horowpathana, Higurakgoda, Dimbulagala | Water sourcing, diet, risk perception, CKDu awareness | Local habits and preventive awareness |
| **Regional Policymakers** | 10 | Various sectors | Governance frameworks, food/water/environment policies | Structural/regulatory challenges |

These interview surveys explored the lived experiences of individuals in CKDu-endemic communities, focusing on their beliefs about disease causation, experiences with health systems, water usage practices, and their views on agrochemical use and regulation. Semi-structured interviews are well-suited for exploring complex, context-specific health and environmental issues, particularly when local cultural, institutional, or policy factors are involved (Bryman, 2016; Creswell & Poth, 2018).

Data from both the surveys and interviews were coded and analysed to identify emerging themes related to CKDu exposure, knowledge gaps, and the interplay between environmental and social risk factors. This qualitative component was critical to designing culturally sensitive and contextually appropriate policy recommendations.

### 3.4 Laboratory Testing Procedures

Laboratory analyses were conducted at the Horticultural Crops Research and Development Institute (HCRDI), under standardized protocols for sample handling, analytical precision, and instrument calibration, ensuring high data reliability (ISO/IEC 17025:2017). All procedures adhered to international and national guidelines.

#### 3.4.1 Water Quality Index (WQI) Determination

To comprehensively assess water quality in regions affected by chronic kidney disease of unknown Etiology (CKDu), the Water Quality Index (WQI) was employed. The WQI consolidates various physicochemical parameters into a single numerical value, facilitating a simplified representation of water quality and its potential health risks (Ewaid et al., 2018).

Ten parameters were selected based on their direct implications for human health and documented associations with renal dysfunction.

*Table 3.3: Water Quality Parameters and Their Renal Health Impacts Relevant to CKDu*

| Parameter | Threshold/Concern Level | Level<br>Health Impact (Renal Focus) | Source |
|---|---|---|---|
| **pH** | Outside 6.5–8.5 | Increases the solubility of heavy metals, ↓ **nephrotoxic risk** | WHO, 2011 |
| **Dissolved Oxygen (DO)** | Below 5 mg/L | Indicates organic pollution ↓ microbial growth, ↓ **Potential renal infections** | APHA, 2017 |
| **Biological Oxygen Demand (BOD)** | Elevated levels | High organic matter ↓ microbial contamination ↓ **kidney infections** | APHA, 2017 |
| **Nitrate ($NO_3^-$)** | Above 50 mg/L | Causes oxidative stress ↓ **Nephrotoxicity** | WHO, 2011 |
| **Turbidity** | High levels | Harbors pathogens/heavy metals ↓ Indirect renal health impact | WHO, 2011 |
| **Total Dissolved Solids (TDS)** | Above 500 mg/L | Increases renal filtration burden ↓ **kidney stones, CKD progression** | WHO, 2011 |
| **Temperature** | Elevated temperatures | Promotes microbial proliferation ↓ **Increased kidney infection risk** | APHA, 2017 |
| **Arsenic (As)** | Above 0.01 mg/L | Linked to proteinuria and **chronic kidney disease (CKD)** | WHO, 2011 |
| **Cadmium (Cd)** | Above 0.003 mg/L | Causes tubular dysfunction ↓ **Irreversible renal damage** | WHO, 2011 |
| **Lead (Pb)** | Above 0.01 mg/L | Associated with interstitial **nephritis**, reduced glomerular filtration rate | WHO, 2011 |

**Sample Collection and Analysis**

Fifty water samples were collected from five locations within each CKDu hotspot. Samples were filtered using Whatman No. 42 filter paper to remove suspended solids. To stabilize metal ions and inhibit microbial activity, samples were acidified to pH < 2 with concentrated nitric acid ($HNO_3$), following protocols recommended by the United States Environmental Protection Agency (USEPA, 1994) and the American Public Health Association (APHA, 2017). Samples were stored in high-density polyethylene bottles at 4°C until analysis.

Quantitative analysis of heavy metals (As, Cd, Pb) was conducted using a PerkinElmer Analyst 400 Flame Atomic Absorption Spectrophotometer (AAS)(detailed methodology provided in Appendix E). Calibration curves were prepared using certified reference standards, and each element was analyzed at its optimal resonance wavelength: Cd at 228.8 nm, Pb at 283.3 nm, and As at 193.7 nm. Analytical accuracy and precision were ensured by including reagent blanks, duplicate samples, and reference materials (USEPA, 1994).

**WQI Calculation Methodology**

The WQI was calculated using the Weighted Arithmetic Index method, comprising the following steps:

**a. Assignment of Weights (Wi):**

Each parameter was assigned a weight (Wi) reflecting its relative importance to overall water quality and potential health impact. Parameters with significant nephrotoxic effects were given higher weights, as shown in Table 3.4.

*Table 3.4: Assigned Weights for Water Quality Parameters*

| Parameter | Weight (Wi) | Parameter | Weight (Wi) |
|---|---|---|---|
| **pH** | 3 | **TDS** | 4 |
| **DO** | 3 | **Temperature** | 2 |
| **BOD** | 3 | **Arsenic** | 5 |
| **Nitrate** | 3 | **Cadmium** | 5 |
| **Turbidity** | 3 | **Lead** | 5 |

**b. Quality Rating Scale (Qi):**

For each parameter, a quality rating (Qi) was calculated using the formula:

***Eq. (3.1), where each parameter's concentration is compared to its standard.***

$$Q_i = \left(\frac{C_i}{S_i}\right) \times 100 \qquad (3.1)$$

Where:

- Ci = Measured concentration of the ith parameter.
- Si = WHO standard permissible limit for the ith parameter.

For DO, since lower values indicate poorer quality, the formula was adjusted

***Equation 3.2: Adjusted Quality Rating for Dissolved Oxygen (DO)***

$$Q_{DO} = \left(\frac{S_i}{C_i}\right) \times 100 \qquad (3.2)$$

**c. Sub-Index Calculation (SIi):**

Each parameter's sub-index (SIi) was computed by multiplying its weight by the quality rating:

***Equation 3.3: Sub-Index Calculation for Individual Water Quality Parameters***

$$SI_i = W_i \times Q_i \qquad (3.3)$$

**d. Overall WQI Calculation**:

The overall WQI was determined using the formula:

*Equation 3.4: Final Water Quality Index (WQI) Calculation*

$$WQI = \frac{\sum SI_i}{\sum W_i} \qquad (3.4)$$

**d. Interpretation of WQI Values:**

The WQI values were interpreted as per the classification in Table 3.5.

*Table 3.5: WQI Interpretation Scale*

| WQI Range | Water Quality Description |
|---|---|
| **0–50** | Excellent |
| **51–100** | Good |
| **101–200** | Poor |
| **201–300** | Very Poor |
| **>300** | Unsuitable for Consumption |

### 3.4.2 Soil Pollution Load Index Determination

**Sample Preparation and Analytical Procedure.**
To assess the potential contribution of soil contamination to Chronic Kidney Disease of Unknown Etiology (CKDu) in Sri Lanka's agricultural regions, this study focused on quantifying soil concentrations of cadmium (Cd), arsenic (As), and lead (Pb), alongside Soil PH. These parameters were selected due to their known nephrotoxic effects and environmental persistence in agroecosystems (Alloway, 2013).
Soil samples were collected from agricultural fields in ten identified CKDu hotspot areas. Samples were air-dried at ambient temperature, homogenized, and sieved through a 2 mm mesh. For heavy metal extraction, 0.5 g of each soil sample underwent acid digestion using a tri-acid mixture ($HNO_3$:$HClO_4$:$H_2SO_4$ in a 5:1:1 ratio), following the protocols outlined in USEPA Method 3050B . The digested samples were filtered and diluted with deionized water to a final volume of 50 ml.
Heavy metal concentrations (Cd, As, Pb) were quantified using Flame Atomic Absorption Spectrophotometry (FAAS) with appropriate wavelength settings: Cd (228.8 nm), As (193.7 nm), and Pb (217.0 nm). Calibration was performed using certified standard solutions, and quality assurance included reagent blanks and certified reference materials (IAEA-Soil-7). All values were reported in mg/kg dry weight.

**Soil pH Measurement**
Soil pH influences heavy metal solubility and mobility; acidic soils (pH < 6.5) can increase metal availability and toxicity (Kabata-Pendias, 2011). Soil pH was measured using the 1:2.5 soil-to-water suspension method. Specifically, 10 g of dried soil was mixed with 25 mL of distilled water, shaken for 30 minutes, and left to settle before pH measurement using a calibrated digital pH meter.

**Pollution Load Index (PLI) Calculation Based on Contamination Risk**

To evaluate pollution risk, the Soil Quality Index (SQI) was adapted using the Contamination Factor (Cf) and Pollution Load Index (PLI), methods widely used for ecological risk assessment in contaminated soils.

**Contamination Factor (Cf):**

***Equation 3.5: Contamination Factor Equation***

$$Cf_i = \frac{C_i}{C_{ref}} \qquad (3.5)$$

Where:

- $C_i$ = Measured concentration of heavy metal *i*
- $C_{ref}$ = Background/reference value of metal *i*

Reference values used were Cd = 0.5 mg/kg, As = 10 mg/kg, and Pb = 50 mg/kg (Alloway, 2013; WHO, 2011).

**Pollution Load Index (PLI):**

***Equation 3.5: Pollution Load Index Equation***

$$\boldsymbol{PLI = (Cf_{Cd} \times Cf_{As} \times Cf_{Pb})^{1/3}}$$

PLI provides a cumulative index of pollution:

- PLI < 1: Unpolluted
- PLI = 1: Baseline level
- PLI > 1: Progressive deterioration of soil quality

(Varol, 2011)

## 3.5 Development and Implementation of a Food Policy Framework Based on Empirical Findings.

Building upon the empirical data collected, a comprehensive food policy was formulated to mitigate CKDu risks through evidence-based interventions.

### 3.5.1 Risk Identification

Laboratory analyses identified zones with elevated Water Quality Index (WQI) and Soil Pollution Load index (PLI) values, indicating high contamination levels. Cross-referencing these findings with survey data facilitated the identification of vulnerable communities and high-risk behaviours, such as reliance on contaminated water sources and unsafe agricultural practices. This integrative approach is consistent with global best practices in environmental health risk assessments.

### 3.5.2 Exposure Pathway Mapping

Exposure pathways were mapped to understand how contaminants from water and soil enter the human body, primarily through drinking water, crop irrigation, and soil-to-plant transfer. This mapping is crucial for pinpointing intervention points and has been effectively utilized in similar environmental health studies.

### 3.5.3 Policy Development Components

Based on the identified risks and exposure pathways, the following policy components were developed:

***Table 3.6: Integrated Community-Based Intervention Strategies for CKDu Prevention and Environmental Risk Reduction.***

| Intervention Area | Strategy Description | Target Group | Expected Impact |
|---|---|---|---|
| **Water Interventions** | Community-based treatment systems (e.g., reverse osmosis), restrict contaminated well use | Households in high-risk zones | Reduced exposure to nephrotoxic metals in drinking water |
| **Soil Remediation** | Promote crop rotation, reduce harmful agrochemical use | Smallholder farmers | Long-term reduction in soil contamination and safer food production |
| **Food Safety Zoning** | Label food origins based on contamination risk; establish safe production zones | Consumers, Agricultural authorities | Increased consumer awareness and regulation of high-risk agricultural zones |
| **Public Education** | Localized awareness campaigns on CKDu risks and prevention | General public, schoolchildren, farmers | Improved understanding of CKDu etiology and risk reduction behaviors |
| **Behaviour Change Support** | Provide incentives for clean water use and eco-friendly farming practices | Farmers, low-income communities | Increased adoption of sustainable practices and reduced CKDu-related vulnerabilities |

### 3.5.4 Monitoring and Evaluation

To ensure the effectiveness and sustainability of the policy interventions, a robust monitoring and evaluation framework was established, encompassing:

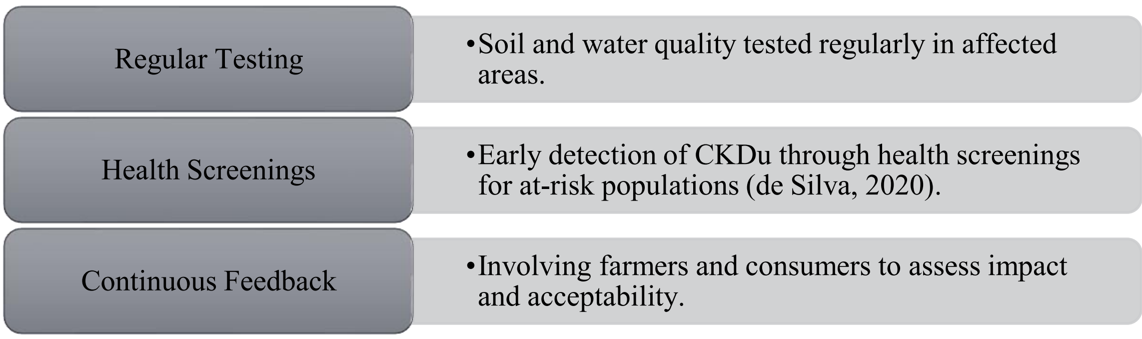


***Figure 3.14: Monitoring and Evaluation Framework for Policy Interventions***

This comprehensive approach ensures that the policy remains responsive to emerging data and community needs, aligning with global standards for public health interventions.

### 3.6 Key Fieldwork Challenges

Despite meticulous planning, several logistical and contextual challenges were encountered during the fieldwork phase, affecting both survey administration and environmental sample collection in CKDu-endemic regions.

#### 3.6.1 Language and Communication Barriers

The primary language spoken in the surveyed rural areas was Sinhala, with certain communities using regional dialects. These linguistic differences posed challenges in ensuring clarity and accuracy in data collection. To overcome this, trained local translators were engaged during interviews and survey administration. Visual aids, including pictograms and simplified illustrations, were employed to communicate complex technical terms—especially those relating to agrochemicals, toxicity, and chronic health conditions—to participants with limited scientific literacy.

#### 3.6.2 Climatic Constraints

Field activities were conducted under challenging climatic conditions typical of Sri Lanka's dry zone. Temperatures frequently exceeded 35°C, and sporadic monsoon rains further disrupted survey schedules and sample collection.

#### 3.6.3 Literacy and Knowledge Gaps

Many respondents, especially older farmers, displayed limited literacy and minimal awareness of the health risks associated with agrochemical exposure. This knowledge gap necessitated the use of context-specific explanations and rephrasing of technical questions into locally understandable formats.

#### 3.6.4 Logistical and Transportation Challenges

The remoteness and poor infrastructure of certain sampling sites significantly impeded accessibility. Field teams often had to traverse long distances through rugged terrain, resulting in delays in sample transportation and increased logistical burden.

#### 3.6.5 Community Engagement and Trust

Initial encounters with several communities were marked by scepticism and mistrust toward the research team. This hesitation was largely due to unfamiliarity with external researchers and concerns about the implications of the study. To address this, local leaders, including village officers (Grama Niladharis) and religious figures, were engaged early in the process.

# 4. Analysis of Water, Soil, and Socio-Behavioral Data in CKDu Hotspot Areas.

## 4.1 Interpreting Empirical Evidence for Food Policy Action.

This section provides an integrated analysis of the empirical data collected through environmental testing, structured household surveys, key informant interviews, and field observations across CKDu-affected regions in Sri Lanka. The purpose of this analysis is to identify critical patterns and exposure pathways that inform the development of evidence-based food policy interventions.

The data are synthesized under three principal themes:

1. Survey and Interview Findings.
   This subsection analyses both quantitative and qualitative insights from 100 participants across ten CKDu-endemic areas. The data reveal key behavioural patterns, agricultural practices, water usage habits, and levels of awareness about CKDu risk factors. These insights help elucidate socio-environmental dynamics that contribute to disease vulnerability.
2. Water and Soil Quality Analysis
   This component presents the findings from laboratory analysis of environmental samples, employing Water Quality Index (WQI) and Soil Pollution Load Index (PLI) methodologies. The results provide an objective assessment of environmental contamination, including the presence of nephrotoxic elements such as arsenic, cadmium, and lead.
3. Practical Field Observations
   This subsection documents observational data collected during fieldwork, including local agricultural behaviours, water access conditions, and community health practices. These observations complement the analytical data and highlight contextual nuances relevant to CKDu mitigation.

The triangulation of these datasets enables a comprehensive understanding of the environmental and behavioural determinants of CKDu. More importantly, the findings presented here serve as the empirical foundation for policy formulation, specifically in the areas of food safety, agrochemical regulation, water management, and public health communication. The ultimate goal of this analysis is to translate scientific evidence into actionable food policy strategies to address CKDu in Sri Lanka.

## 4.2 Survey and Interview Findings

### 4.2.1 Survey Execution and Data Collection

To gain insights into environmental exposure, behavioural patterns, and health awareness relevant to CKDu, a structured community survey was conducted in ten identified hotspot areas across the Anuradhapura and Polonnaruwa districts of Sri Lanka. A total of 100 participants were selected through purposive sampling, comprising farmers, agricultural workers, and household heads whose livelihoods are closely tied to agricultural activities.

The survey instrument was designed to collect qualitative data and was administered in the local language (Sinhala) by trained enumerators. The primary domains of inquiry included:

*Table 4.1: Thematic Domains Covered in the Community Survey on CKDu Risk Factors*

| Domain | Description | Indicators Assessed |
|---|---|---|
| **Agrochemical Use** | Evaluates the type, frequency, and manner of agrochemical use among participants. | - Types of pesticides and fertilizers used<br>- Application frequency<br>- PPE usage and handling/storage practices |
| **Water Sourcing and Usage** | Investigate household-level access to and use of water for domestic and agricultural purposes. | - Primary drinking water source<br>- Irrigation methods<br>- Seasonal variability and treatment practices |
| **Health Knowledge & Disease Perception** | Explores awareness of CKDu symptoms and its perceived causes within the community. | - Knowledge of CKDu symptoms<br>- Awareness of agrochemical risks<br>- Engagement in preventive behaviours |
| **Food Storage and Safety** | Assess grain storage practices and contamination of hazardous chemicals risks in food handling. | - Use of traditional vs. modern storage methods<br>- Exposure to pests or chemicals during storage |
| **Healthcare Accessibility** | Reviews the availability and adequacy of healthcare services for kidney-related issues. | - Distance to nearest health centre<br>- Frequency of visits - Satisfaction with services provided |

### 4.2.2 Farmer Survey: Comprehensive Analysis of Agricultural Practices and Health Risks

A structured survey was conducted among 50 farmers—five from each of the ten identified CKDu hotspot regions in Anuradhapura and Polonnaruwa districts—to evaluate key socioeconomic, agricultural, and health-related factors that may contribute to the onset and progression of Chronic Kidney Disease of Unknown Etiology (CKDu). The findings are presented under thematic categories relevant to food policy development.

**Demographic Characteristics**

The age of farmer respondents ranged from 26 to 65 years, with a mean age of approximately 45 years. Males constituted 60% of the sample, while females made up the remaining 40%. Educational attainment varied considerably: 40% had no formal education, 35% had completed primary or secondary school, and 25% had received higher education qualifications.

**Farming Experience and Income Distribution**

Participants reported an average of 24 years of farming experience, with a range from 1 to 40 years. Monthly income levels indicated that 45% of farmers fell into the low-income category (less than LKR 30,000), 30% were moderate-income earners (LKR 30,000–60,000), and 25% earned above LKR 60,000 monthly.

### Agrochemical Usage and Protective Practices

Fertilizer application frequency showed that 60% of farmers applied fertilizers daily, 20% weekly, and 20% monthly or less. In terms of fertilizer type, 44% used only organic inputs, 36% relied solely on chemical fertilizers, and 20% applied both. Despite high exposure, only 62% of farmers reported consistent use of protective gear (e.g., gloves, masks), while 38% applied agrochemicals without any protective equipment.

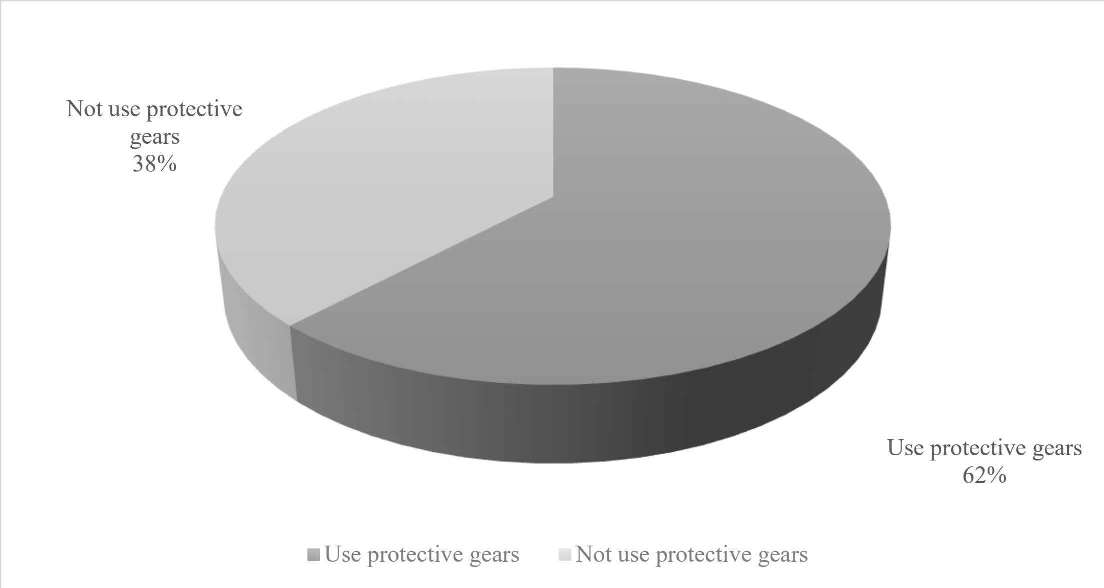


***Figure 4.1: Use of Protective Equipment Among Surveyed Farmers***

### CKDu Awareness and Health-Seeking Behaviour

Only 50% of surveyed farmers were aware that agrochemical exposure could lead to adverse health outcomes, and a mere 18% specifically associated such exposure with kidney disease. Notably, 38% reported a family history of CKDu or related symptoms such as fatigue, lower back pain, or swelling. Among symptomatic individuals, 68% sought formal medical attention, while 32% relied on traditional remedies or refrained from seeking care altogether.

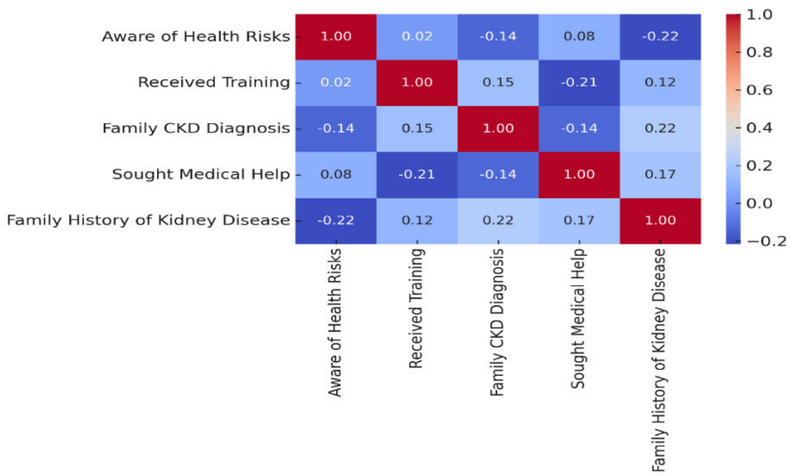


***Figure 4.2: Correlation Matrix of Health Awareness and CKDu-Related Risk Factors Among Agricultural Communities.***

This figure presents the Pearson correlation coefficients among selected variables related to health awareness and kidney disease indicators, based on survey data.

***Table 4.2: Key findings in the Correlation Matrix of Health Awareness and CKDu-Related Risk Factors Among Agricultural Communities.***

| Variable Pair | Correlation (r) | Strength & Direction | Interpretation |
|---|---|---|---|
| Family CKD Diagnosis & Family History of Kidney Disease | 0.22 | Weak Positive | Slight association, indicating potential genetic or household-level linkages. |
| Sought Medical Help & Family History of Kidney Disease | 0.17 | Weak Positive | Individuals with a family history of CKD are modestly more likely to seek care. |
| Sought Medical Help & Family CKD Diagnosis | -0.14 | Weak Negative | Not all individuals with family CKD history seek medical help. |
| Received Training & Sought Medical Help | -0.21 | Moderate Negative | Training may not be effectively driving health-seeking behavior. |
| Aware of Health Risks & Family History of Kidney Disease | -0.22 | Weak Negative | Awareness may be growing among unaffected households. |
| Other Variable Pairs | | Very Weak/Negligible | Minimal linear relationships observed; other factors may be influencing behaviour. |

**Water Source and Treatment Practices**

Primary drinking water sources varied, with 52% using bottled water, 30% depending on community wells, and 18% sourcing from taps or rivers. Among those using untreated water, only 36% reported consistent treatment practices (e.g., boiling or filtering), whereas 64% admitted to rarely or never treating their water.

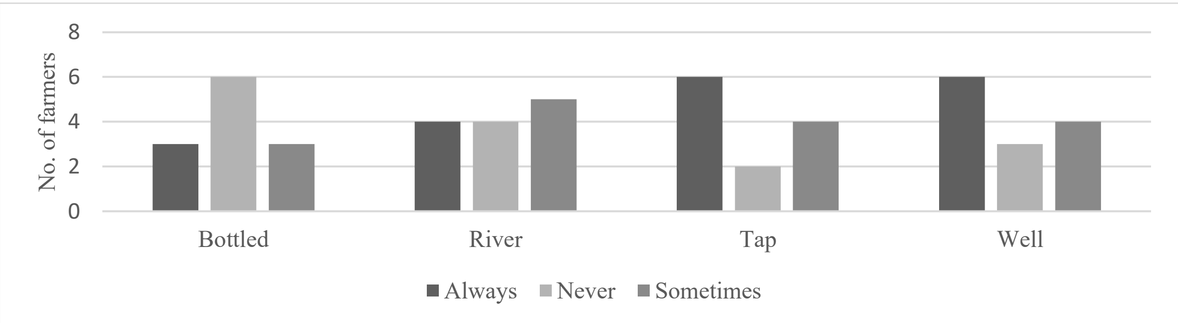


***Figure 4.3: Distribution of water treatment frequency (Always, Never, Sometimes) based on the source of drinking water.***

**Occupational Heat Exposure and Hydration**

A significant proportion (62%) of farmers reported daily exposure to high temperatures. Among them, 42% practiced regular hydration, yet only 24% used protective measures such as wide-brimmed hats or shaded rest breaks.

**Dietary Patterns and Food Safety**

Dietary data showed that 88% of farmers consumed rice and vegetables daily, while 58% regularly included meat or processed foods. Although 68% washed vegetables before consumption, only 28% used treated water for this purpose. Meal frequency varied: 48% consumed three or more meals per day, 32% had two meals, and 20% had just one.

**Illustrative Case Vignettes**

- A 54-year-old female farmer from Kebithigollewa applies chemical fertilizers weekly without any protective gear, consumes bottled water, but experiences fatigue and frequent urination without ever undergoing a kidney screening.
- A 38-year-old male farmer from Elahera uses organic fertilizer daily, treats well water regularly, and consumes a typical diet of rice and vegetables. He remains asymptomatic but reports a family history of CKD.

**Implications for Food Policy Development**

Findings from this farmer-specific survey highlight several critical areas for policy intervention:

***Table 4.3: Policy Implications Derived from Farmer Survey Findings on CKDu Risk Factors***

| Policy Focus Area | Key Findings from Survey | Recommended Policy Action |
|---|---|---|
| **Targeted Education Campaigns** | Only about 50% of farmers are aware of CKDu health risks. | Launch community-level education on agrochemical safety, protective equipment use, and water sanitation. |
| **Integration of Healthcare Services** | Over one-third reported symptoms or family history of CKD. | Introduce mobile screening units and embed health services into agricultural extension programs. |
| **Enhanced Water Safety Infrastructure** | High reliance on untreated water sources for drinking and household use. | Install community water purification systems or provide subsidies for household filtration units. |
| **Occupational Health Standards** | Many farmers work without heat protection or hydration practices. | Develop regulations mandating shaded rest areas, hydration access, and scheduled breaks for outdoor laborers. |
| **Promotion of Food Hygiene** | Untreated water is often used for washing vegetables and produce. | Build communal vegetable washing facilities and educate farmers on safe food handling and hygiene practices. |

A detailed version of the survey instrument is provided in **Appendix A**, offering the full scope of questions and response formats used during data collection.

### 4.2.3 Insights from Agricultural Input Suppliers: Practices, Awareness, and Policy Implications

**Supplier Demographics and Product Categories**

The surveyed agricultural input suppliers, located across the ten CKDu hotspot regions, reported operational experience ranging from 5 to 20 years. Based on their product offerings, they were grouped into three categories:

- **Chemical-only suppliers** (n = 5)
- **Organic-only suppliers** (n = 2)
- **Mixed-input suppliers** (chemical and organic) (n = 8)

The majority (n = 9) catered primarily to small-scale farmers, while others served large-scale growers (n = 2) or agro-industrial clients (n = 2). Suppliers catering to smallholder farmers were more likely to promote organic alternatives, with a supplier in Kahatagasdigiliya reporting tailored offerings such as compost and biofertilizers.

**Agrochemical Distribution and Awareness of Hazards**

The most distributed chemical inputs included Urea, Muriate of Potash (MOP), and Glyphosate, while organic inputs included compost, neem-based biopesticides, and microbial biofertilizers. Despite the widespread distribution of chemical inputs:

- 10 out of 15 suppliers acknowledged awareness of health and environmental risks.
- Only 7 suppliers provided safety instructions to customers at the point of sale.
- Just 6 suppliers had received formal training in risk communication or safe handling.

This illustrates a significant awareness-implementation gap, as exemplified by a Padaviya supplier who admitted to selling glyphosate without safety training or user guidance.

**Regulatory Awareness and Perceived Effectiveness**

Only a minority of suppliers (n = 5) were aware of key agricultural regulations, such as the Pesticide Control Act. Even fewer (n = 4) believed existing policy frameworks were effective, citing issues such as:

- Poor enforcement
- Inconsistent inspections
- Limited outreach or engagement from authorities

One respondent from Rambewa described the act as "irrelevant" in practice, due to the absence of local monitoring.

**Operational Challenges in Promoting Safer Inputs**

Suppliers identified several market and logistical challenges:

- High costs of agrochemical inputs (n = 4)
- Limited availability of certified organic alternatives (n = 3)
- Low demand from farming communities (n = 3)
- Lack of awareness among consumers (n = 3)

A supplier in Medirigiriya highlighted the difficulty of maintaining organic fertilizer stock despite growing interest, pointing to supply-chain constraints.

**Shifting Market Preferences and Potential for Policy Support**

Despite these barriers, 8 suppliers noted a gradual shift in farmer preferences toward sustainable and lower-toxicity inputs. However, only 4 respondents reported awareness of government incentives to promote this transition. This reflects a potential gap in policy communication and support mechanisms.

**Recommendations from the Supply Sector**

Suppliers suggested several key interventions:

- **Farmer education and awareness programs** (n = 7)
- **Stronger regulatory enforcement** (n = 5)
- **Incentives for organic production and retailing** (n = 4)
- **Government procurement/subsidy systems** for safer products (n = 2)

A respondent in Elahera proposed state-supported **training and subsidy schemes** to encourage smallholder adoption of organic practices.

**Sectoral Reflections on CKDu**

There was a high degree of concern regarding the CKDu crisis:

- 10 of 15 suppliers expressed willingness to engage with public health and environmental programs.
- 9 suppliers acknowledged the sector's role in influencing agrochemical exposure and thus, indirectly, CKDu prevalence.
- However, only 3 had faced any regulatory penalties, highlighting systemic lapses in compliance and enforcement.

Several respondents, particularly in **Hingurakgoda** and **Kahatagasdigiliya**, recommended policy innovations such as:

- **Supplier certification schemes**
- **Tax incentives** for promoting low-risk agricultural inputs

These suggestions align closely with the thesis objective of developing a preventive food policy framework for CKDu mitigation.

### 4.2.4 Perspectives from Healthcare Providers: Clinical Insights into CKDu and Policy Implications

**Professional Profiles and CKDu Training**

The surveyed healthcare professionals—comprising medical doctors, public health officers, and nurses—had professional experience ranging from 4 to 22 years. Notably, over 60% of respondents had been engaged in healthcare delivery for more than a decade. While most doctors and public health officers had received formal training on Chronic Kidney Disease of Unknown Etiology (CKDu), nurses often reported limited or no specific training. This discrepancy underscores a critical gap in the continuity of care and highlights the need for inclusive, multidisciplinary CKDu training across all tiers of healthcare personnel.

**CKDu Case Burden and Clinical Exposure**

All respondents had experience managing CKDu cases, with some physicians reporting over 100 patients per year. Public health officers and nurses handled between 10 and 100 cases annually, reflecting the widespread prevalence and clinical workload associated with CKDu in endemic areas. The disease's burden is particularly pronounced in rural divisions where diagnostic and treatment resources are limited.

**Symptomatology and Diagnostic Constraints**

The most frequently reported symptoms included:

- **Fatigue**
- **Lower limb edema (swelling)**
- **Lower back pain**
- **Oliguria or reduced urine output**

Respondents cited major diagnostic limitations:

- **Asymptomatic early stages**, often resulting in delayed diagnosis
- **Inadequate diagnostic facilities**, especially in rural peripheral hospitals
- **Poor health literacy and low disease awareness**, contributing to late clinical presentation

A significant concern highlighted by doctors and public health officers was that late-stage diagnosis remains a primary barrier to effective disease management and improved outcomes.

**Risk Profiles and Exposure Trends**

Healthcare providers consistently identified the following high-risk groups:

- **Paddy farmers**, due to direct agrochemical handling
- **Male field workers**, attributed to longer outdoor exposure
- **Individuals with chronic agrochemical exposure** and low socioeconomic status

Environmental conditions such as **chronic dehydration, especially during the Yala (dry) season**, were repeatedly emphasized as exacerbating disease progression. Providers noted that limited hydration during long work hours and inadequate rest under high ambient temperatures are potential co-factors in renal decline.

**Treatment Modalities and Outcome Variability**

The therapeutic approach to CKDu was predominantly symptomatic and supportive, encompassing:

- **Dialysis**
- **Pharmacotherapy**
- **Nutritional and lifestyle modifications**, such as increased hydration and dietary regulation

Reported recovery rates varied from 25% to 60%, while mortality rates ranged between 30% and 65%, with most clustered around 50%. These figures demonstrate the significant burden CKDu places on local health systems and the low probability of full recovery without early detection and specialized care.

**Preventive Strategies and Resource Limitations**

When asked about CKDu prevention, respondents prioritized:

- **Reducing agrochemical exposure**
- **Improving access to clean drinking water**
- **Community education on hydration and early symptom detection**

However, 13 out of 15 respondents reported insufficient infrastructure to manage CKDu effectively. Identified deficiencies included:

- **Lack of screening and diagnostic kits**
- **Limited dialysis availability**
- **Absence of structured educational programs**

- 

This indicates an urgent need for capacity-building in rural health facilities and the integration of CKDu screening within broader public health programs.

**Environmental Stressors and Health Impacts**

All participants acknowledged the link between environmental heat stress and CKDu symptom aggravation, particularly during Sri Lanka's dry season. Long hours of agricultural labor under extreme heat, coupled with insufficient hydration, were consistently linked to faster disease progression, underscoring the environmental-occupational dimension of CKDu.

**Policy Recommendations and Public Health Integration**

Insights from healthcare providers revealed the necessity for a **multilevel policy framework** integrating environmental health, occupational safety, and disease prevention.

***Table 4.4: Priority Recommendations for Enhancing CKDu Management and Prevention***

| Recommendation | Target Group | Purpose | Expected Outcome |
|---|---|---|---|
| **Expanded training programs for frontline caregivers, including nurses** | Nurses, PH officers, rural doctors | Improve CKDu diagnosis and patient care capabilities | Enhanced early detection and standardized clinical response |
| **Infrastructure enhancement in rural clinics, with diagnostic and treatment upgrades** | Rural healthcare centres | Address equipment and capacity gaps in CKDu-affected regions | Increased access to dialysis, lab testing, and patient follow-up |
| **Community-level CKDu awareness campaigns, particularly in farming regions** | Farming communities | Promote health-seeking behavior and preventive practices | Earlier symptom reporting and reduced disease progression |
| **Mobile screening units and early intervention programs for at-risk populations** | At-risk rural populations | Enable proactive diagnosis and reduce rural-urban healthcare disparities | Higher screening coverage and improved disease outcomes |

**Food Policy Relevance: Medical Perspectives**

Healthcare providers unanimously attributed CKDu to prolonged exposure to agrochemicals, particularly among agricultural workers. Their clinical observations support the integration of health risk considerations into food policy, with key implications.

*Table 4.5: Clinical Insights Informing Food Policy Recommendations on CKDu*

| Observation | Policy Implication | Suggested Action |
|---|---|---|
| **Prolonged agrochemical exposure is a key driver of CKDu among agricultural workers** | Regulatory oversight of chemical inputs in food production | Enforce stricter controls on pesticide and fertilizer approval, labeling, and distribution |
| **Consistent link between toxic exposure and kidney dysfunction observed in clinical settings** | Integration of toxicological risk assessments into agrochemical approval processes | Mandate chronic toxicity testing and health impact evaluations prior to market release |
| **Higher incidence of CKDu among conventional (non-organic) farming communities** | Promotion of organic farming and safer agrochemical alternatives | Provide subsidies, certification schemes, and market incentives for organic and low-toxicity inputs |

These perspectives reinforce the need for cross-sectoral collaboration between health and agriculture, establishing a foundation for preventive food policies that protect vulnerable rural populations from occupational and dietary nephrotoxins.

**Food Safety and Water Quality as Public Health Priorities**

Healthcare providers consistently identified poor water quality as a critical co-factor in the progression of CKDu, underscoring the interconnectedness between water, food, and health systems. Since water serves not only as a drinking source but also for irrigation and post-harvest processing, the findings reinforce the necessity to embed water safety within broader food policy frameworks. Key recommendations include:

- Integration of water safety standards into all stages of food production and processing.
- Implementation of community-based water purification systems, particularly in CKDu-endemic agricultural zones.
- Routine monitoring of irrigation and domestic water sources to prevent food contamination and chronic exposure to nephrotoxic agents.

**Nutritional and Lifestyle Interventions**

Clinical practitioners emphasized the role of diet and hydration in CKDu prevention and management. These insights highlight an opportunity for food policy to adopt a preventive public health lens. Specific strategies include:

- Developing and disseminating nutrition education programs targeting rural and farming communities.
- Encouraging the cultivation and consumption of nutrient-dense, low-toxin crops.
- Aligning national food aid, school meal plans, and rural food security programs with CKDu-specific dietary guidelines.

**Health Infrastructure as a Food Policy Concern**
A lack of diagnostic tools, treatment facilities, and trained health personnel was frequently reported as a barrier to effective CKDu management. Although traditionally siloed, food policy can actively support health system strengthening through:

- Advocating for integrated health-agriculture budgeting in regions with high CKDu prevalence.
- Supporting mobile health clinics, field-based diagnostic services, and CKDu awareness initiatives as extensions of agricultural outreach programs.

**Climate-Responsive Food Systems**
Clinical feedback also linked heat stress, dehydration, and seasonal labor conditions with increased CKDu susceptibility, especially among male agricultural workers. Food systems, therefore, must respond to these environmental stressors by:

- Promoting climate-adaptive farming practices, including shaded workspaces, hydration stations, and rest periods during peak heat.
- Supporting agroecological methods that reduce chemical dependency and labor intensity, particularly during dry seasons such as Yala.

#### 4.2.5 Community Member Questionnaire: Analysis and Key Findings
**Demographic Characteristics and Vulnerability Profile**

The respondent pool reflected the socioeconomic and occupational profile typical of rural agrarian communities. The majority (60%) were engaged in agriculture, while the remainder were involved in labour-intensive occupations or public sector employment. Low-income levels were prevalent among farmers and daily-wage labourers, rendering these groups particularly vulnerable to both environmental hazards and healthcare inaccessibility. Educational attainment varied, with 10% reporting no formal education and only 20% attaining higher education, which correlated with disparities in access to health information and adoption of preventive behaviours.

**CKDu Household Prevalence and Health-Seeking Behavior**
Notably, 70% of participants reported having at least one household member diagnosed with CKDu, highlighting the high familial disease burden. Awareness of CKDu symptoms—such as fatigue, lower limb swelling, back pain, and altered urination patterns—was higher among individuals with affected family members. However, this did not consistently translate into proactive healthcare-seeking behavior. Most respondents reported irregular or infrequent medical checkups, often citing barriers such as cost, transportation difficulties, and limited trust in public health systems.

**Water Access, Quality, and Treatment Practices**
Household water sources primarily included wells (50%) and municipal tap water (35%), with bottled water being used mainly by higher-income respondents. Water treatment practices were inconsistent and largely informal. Basic methods such as boiling, cloth filtration, and grain sun-drying were observed, but 25% of respondents reported no treatment at all. Seventy-five percent acknowledged a noticeable decline in water quality—citing changes in color, odor, or taste—but continued usage was often due to lack of alternatives. This underlines significant exposure to potential nephrotoxic agents via water.

**Dietary Habits and Nutritional Risks**

Dietary patterns were characterized by low diversity, with a heavy reliance on rice and vegetables. Fruit and processed food consumption was infrequent, and nutritional knowledge—particularly concerning renal health—was limited. Most households consumed two to three meals per day, with minimal understanding of kidney-specific diets. Food hygiene practices, such as vegetable washing, were commonly reported, although adherence varied widely across education and income levels.

**Agrochemical Exposure and Environmental Stressors**

Sixty percent of participants reported direct or indirect exposure to agrochemicals, either through occupational use or consumption of potentially contaminated produce. Concurrently, heat stress and dehydration were widespread among farmers and laborers. Fieldwork often occurred under high-temperature conditions with irregular access to clean drinking water and insufficient rest periods. These occupational hazards represent a significant physiological burden with direct implications for renal function.

**Food and Water Safety Measures**

While some households engaged in rudimentary preventive practices—such as boiling water or using natural filtration agents like ash or alum—these measures were inconsistently applied. Households with higher education or government employment status were more likely to adopt formal safety protocols, including the use of bottled water and adherence to food hygiene. Community-level initiatives, such as shared rainwater tanks, were noted but were infrequent and lacked institutional support.

**Scientific and Policy Relevance**

The findings from this survey reveal critical intersections between food systems, public health, and environmental exposure, reinforcing the need for integrated food policy solutions in CKDu-endemic areas.

***Table 4.6: Community-Level Challenges and Corresponding Food Policy Implications in CKDu-Endemic Regions.***

| Domain | Observed Challenges | Policy Implications |
|---|---|---|
| **Safe Water Access** | Dependence on untreated and deteriorating water sources | Implementation of state-supported water treatment infrastructure and community-level purification systems |
| **Nutrition and Dietary Education** | Monotonous, starch-heavy diets with poor awareness of renal nutrition | Launch of education campaigns on dietary diversity, low-sodium diets, and kidney-specific nutrition guidelines |
| **Agrochemical Risk Mitigation** | Widespread pesticide exposure among community members | Strengthened regulations on agrochemical residues, farmer training, and support for chemical-free cultivation |

| | | |
|---|---|---|
| **Climate Adaptation for Rural Workers** | High rates of dehydration and heat stress among labourers | Integration of occupational safety guidelines, including hydration breaks, shaded rest areas, and climate-sensitive work practices |
| **Surveillance and Community Health Monitoring** | Irregular medical consultations and underdiagnosis | Introduction of mobile health clinics and regular screening programs in high-risk communities |

### 4.2.6 Policymaker's Perspectives on CKDu Mitigation and Food Policy Effectiveness

**Policy Enforcement and Geographic Disparities**

Insights from the policymaker survey revealed pronounced disparities in the enforcement of CKDu-related food and environmental policies across Sri Lanka. While urban centres and administratively central regions demonstrated moderate levels of enforcement (e.g., PM03, PM09), rural and high-risk districts such as Medawachchiya, Elahara, and Padaviya experienced inconsistent or weak enforcement (PM01, PM02, PM04, PM06, PM08, PM10). Respondents attributed these shortcomings to limited manpower, corruption, inadequate budgets, and the absence of locally embedded monitoring systems. These findings are particularly concerning, as rural agrarian populations represent the epidemiological epicentre of CKDu, necessitating urgent and location-specific policy mechanisms.

**Gaps in Existing Policy Frameworks**

Across all responses, there was unanimous agreement that existing policy measures fail to address the multifactorial nature of CKDu. Criticisms were levelled at outdated regulatory frameworks, a lack of CKDu-targeted education, minimal rural outreach, and the absence of real-time data surveillance. Notably, several policymakers (PM05, PM08) highlighted the systemic neglect of food contamination and water safety within current legislative instruments, while others (PM03, PM07) pointed to the inadequate incorporation of scientific research into policymaking. This misalignment between policy design and field realities underscores a critical need for comprehensive, evidence-based reforms.

**Structural and Political Barriers**

The survey also illuminated a range of systemic obstacles impeding policy progress. These included aggressive lobbying from agrochemical industries (PM02, PM07, PM09), poor intersectoral coordination—particularly between the ministries of agriculture and health (PM02, PM05)—and fragmented governance structures that hinder unified action (PM10). Several respondents (PM04, PM10) further identified a lack of farmer representation and field-level feedback in policy formulation processes. Compounding these challenges is a significant data deficit regarding rural CKDu prevalence, limiting the precision and responsiveness of current interventions.

**Climate Change as an Amplifier of Risk**

Policymakers unanimously recognized climate variability as a catalyst for CKDu progression. Rising ambient temperatures, irregular rainfall patterns, and increased dependence on groundwater were noted as exacerbating exposure to nephrotoxins through heat stress and dehydration (PM01, PM03, PM07, PM08). These environmental stressors elevate the risk associated with agrochemical residues and contaminated water sources, demanding the urgent integration of climate resilience into food and agricultural policy design.

**Food Policy: Current Effectiveness and Critical Gaps**

Most respondents characterised existing food policies as either "partially effective" or "inadequate," particularly in their ability to regulate informal markets, address rural applicability, and manage agrochemical residues within food systems (PM02, PM04, PM05). A recurrent theme was the failure of current policies to consider the nexus between food safety and environmental health (PM06, PM10). While some success stories emerged—such as localized enforcement models with community participation (PM09)—these were the exception rather than the rule, suggesting untapped potential for scalable, bottom-up policy innovations.

**Proposed Interventions and Strategic Priorities**

Policymakers offered a suite of recommendations to strengthen CKDu-related policy frameworks, with several key priorities emerging across interviews:

- **Agrochemical Regulation**: Ban high-risk agrochemicals linked to nephrotoxicity (PM01, PM05, PM09), and promote organic alternatives through financial and technical support (PM02, PM03, PM07).
- **Public Health Infrastructure**: Expand access to diagnostic services, mobile testing units, and real-time surveillance systems (PM06, PM08).
- **Community Engagement**: Roll out grassroots education campaigns tailored to rural farming populations (PM04, PM10).
- **Multi-sectoral Integration**: Establish district-level task forces that unite health, agriculture, and environmental governance actors (PM07, PM09).

These strategies reflect a shift toward integrated, locally adaptive models that emphasize both preventive and participatory approaches to CKDu mitigation.

**Interagency Collaboration and Resource Needs**

Resource constraints featured prominently in the responses, with policymakers identifying critical deficits in field-level technologies, rural health budgets, and trained personnel. For instance, PM06 called for enhanced diagnostic and surveillance tools, while PM08 highlighted the absence of dedicated research and development funding for CKDu mitigation. Strong advocacy emerged for inter-ministerial cooperation, including:

- Farmer-inclusive policy review councils
- Health–agriculture–environmental task forces
- Joint public health and food safety research platforms

Such collaborations are seen as essential for the design and implementation of policies that are both scientifically robust and socially grounded.

**Relevance to Food Policy Development**

The survey findings highlight the need to reframe food policy within a broader public health and environmental context.

*Table 4.7: Key Recommendations for Future Food Policy to Mitigate CKDu in Sri Lanka*

| Key Focus Area | Policy Recommendation |
|---|---|
| **Environmental Health** | Integrate safeguards on pesticide and fertilizer regulation to protect environmental and public health |
| **Climate Resilience** | Embed climate-resilient agricultural practices to minimize occupational and environmental health risks |
| **Governance and Enforcement** | Bridge rural–urban enforcement disparities through decentralised governance structures |
| **Education and Behaviour Change** | Prioritise preventive education and behavioral change initiatives targeting high-risk groups |
| **Surveillance and Monitoring** | Institutionalise surveillance systems to monitor chemical residues in food and early indicators of CKDu |
| **Overall, Policy Approach** | Develop a holistic, evidence-informed, and participatory food policy to mitigate CKDu in vulnerable regions |

## 4.3 Water Quality Assessment in CKDu Hotspot Areas

### 4.3.1 Physicochemical Characteristics of Water Samples

The physicochemical properties of water samples collected from selected CKDu-affected regions were analyzed to assess water quality variability and potential health risks. Parameters measured included pH, dissolved oxygen (DO), biological oxygen demand (BOD), nitrates, turbidity, total dissolved solids (TDS), temperature, and concentrations of heavy metals (arsenic, cadmium, and lead). The results are summarized in Table 4.8.

*Table 4.8: Summary of Physicochemical Parameters Across Study Areas*

| Area | pH | DO | BOD | Nitrates | Turbidity | TDS | Temp | (As) | (Cd) | (Pb) | WQI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Medawachchiya** | 6.84 | 4.16 | 3.54 | 13.4 | 6.78 | 460 | 32.8 | 13.4 | 0.48 | 7.2 | 108.12 |
| **Kebithigollewa** | 6.96 | 4.46 | 3.24 | 10.8 | 5.78 | 440 | 31.6 | 13 | 0.38 | 6.88 | 96.79 |
| **Padaviya** | 6.58 | 3.88 | 4.08 | 15.8 | 7.2 | 490 | 31.6 | 16.8 | 0.78 | 6.08 | 127.46 |
| **Rambeva** | 7.08 | 4.34 | 3.74 | 13.66 | 6.22 | 468 | 32.2 | 14.5 | 0.56 | 7.08 | 111.61 |
| **Horowpathana** | 6.68 | 3.98 | 4.16 | 16.8 | 7.78 | 510 | 31.6 | 17.8 | 0.88 | 8.66 | 140.01 |
| **Kahatagasdigiliya** | 6.98 | 4.48 | 3.34 | 12.8 | 6.02 | 459 | 31.8 | 12.8 | 0.34 | 5.64 | 93.79 |
| **Medirigiriya** | 7 | 4.12 | 3.96 | 14.8 | 6.66 | 479 | 31.2 | 15.8 | 0.68 | 6.78 | 119.65 |
| **Dimbulagala** | 6.78 | 3.88 | 4.38 | 17.8 | 7.36 | 520 | 31.6 | 19.8 | 1.08 | 6.86 | 148.94 |
| **Elahera** | 7.18 | 4.52 | 3.08 | 11.8 | 5.62 | 453 | 32.2 | 12.8 | 0.48 | 6.5 | 100.43 |
| **Hingurakgoda** | 6.68 | 3.78 | 4.58 | 18.8 | 7.98 | 549 | 33.2 | 21.8 | 1.28 | 7.16 | 166.14 |

**pH** values ranged from 6.58 (Padaviya) to 7.18 (Elahera), indicating that the water in all sampling locations remained within permissible limits for drinking water. Slightly acidic conditions observed in Padaviya and Horowpathana may enhance the solubility and mobility of heavy metals, thereby potentially increasing their bioavailability in groundwater systems.

**Dissolved Oxygen (DO)** concentrations varied between 3.78 mg/L (Hingurakgoda) and 4.52 mg/L (Elahera). Corresponding **Biological Oxygen Demand (BOD)** values ranged from 3.08 to 4.58 mg/L. Lower DO levels coupled with elevated BOD in areas such as Hingurakgoda and Dimbulagala suggest increased organic pollution, likely attributable to agricultural runoff and domestic wastewater discharge. These conditions may create anoxic environments detrimental to aquatic life and indicative of water quality degradation.

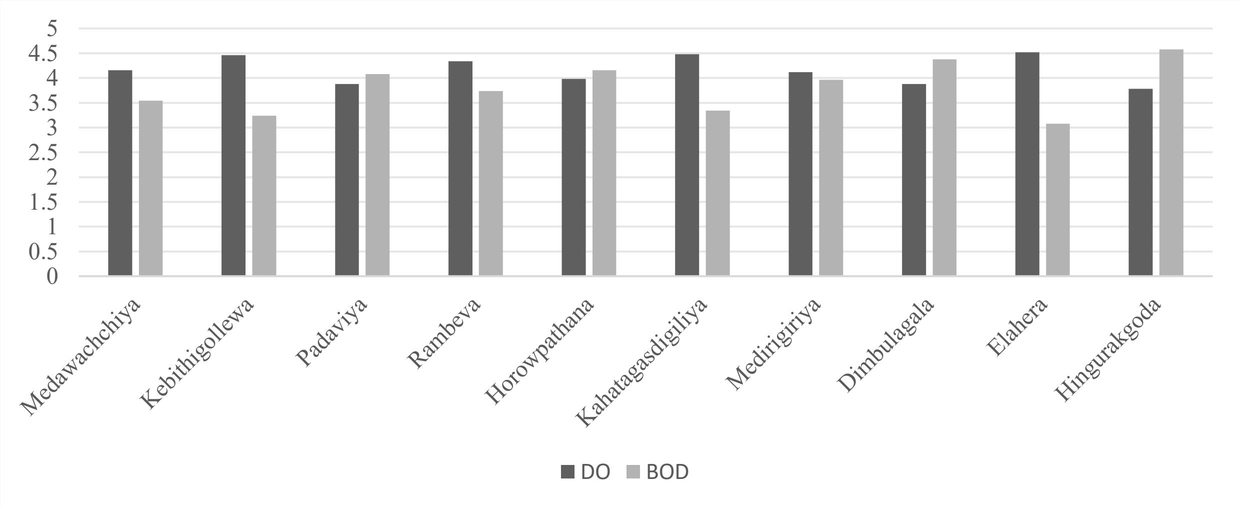

*Figure 4.4: Bar Chart of DO and BOD Levels Across Study Areas*.

**Nitrate concentrations** were elevated across most sites, with the highest values recorded in Hingurakgoda (18.8 mg/L) and Dimbulagala (17.8 mg/L), surpassing recommended guideline values for safe drinking water. Such elevated nitrate levels are commonly associated with intensive fertilizer application and subsequent leaching into groundwater, posing significant health risks including methemoglobinemia and potential nephrotoxicity linked to CKDu.

**Turbidity** values ranged from 5.62 NTU (Elahera) to 7.98 NTU (Hingurakgoda), reflecting the presence of suspended solids and particulate matter. Elevated turbidity can facilitate microbial growth and reduce the effectiveness of disinfection processes.

**Total Dissolved Solids (TDS)** concentrations were relatively high across the study sites, ranging from 440 to 549 mg/L, occasionally exceeding recommended limits for potable water. Elevated TDS levels may result from natural groundwater mineralization or contamination from agricultural and anthropogenic activities, potentially affecting water palatability and health.

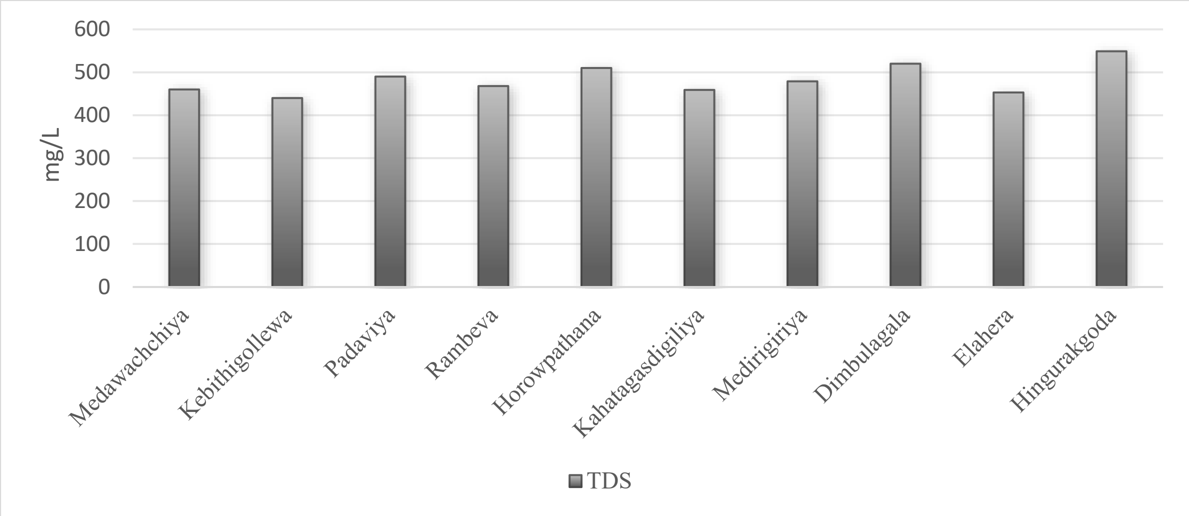


***Figure 4.5: Graph of TDS Concentrations Across Study Areas***

**Temperature** of Water  measurements were relatively uniform across the study sites, ranging from 31.2°C to 33.2°C. Elevated temperatures can affect the solubility of dissolved gases and influence the rates of chemical and biological processes within aquatic systems, thereby indirectly impacting overall water quality and contaminant dynamics.

**Arsenic(As)** concentrations ranged from 12.8 µg/L to 21.8 µg/L, with the highest levels detected at Hingurakgoda. Most sampling locations exceeded the recommended guideline limit of 10 µg/L for arsenic in potable water. Chronic exposure to arsenic-contaminated water is implicated in renal tubular dysfunction and is considered a significant risk factor for CKDu development.

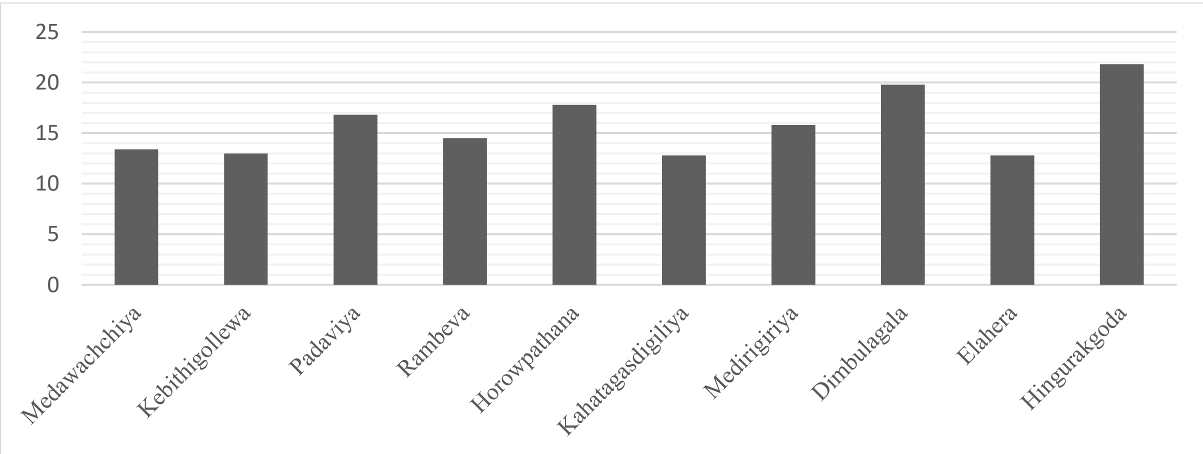


***Figure 4.6:  Arsenic level of concentration in* µg/L**

**Cadmium (Cd)** levels varied between 0.34 µg/L and 1.28 µg/L, peaking at Hingurakgoda. Although concentrations were generally low, several sites recorded values surpassing standard drinking water safety thresholds. Prolonged exposure to even low cadmium concentrations may induce proximal tubular injury and contribute to renal impairment.

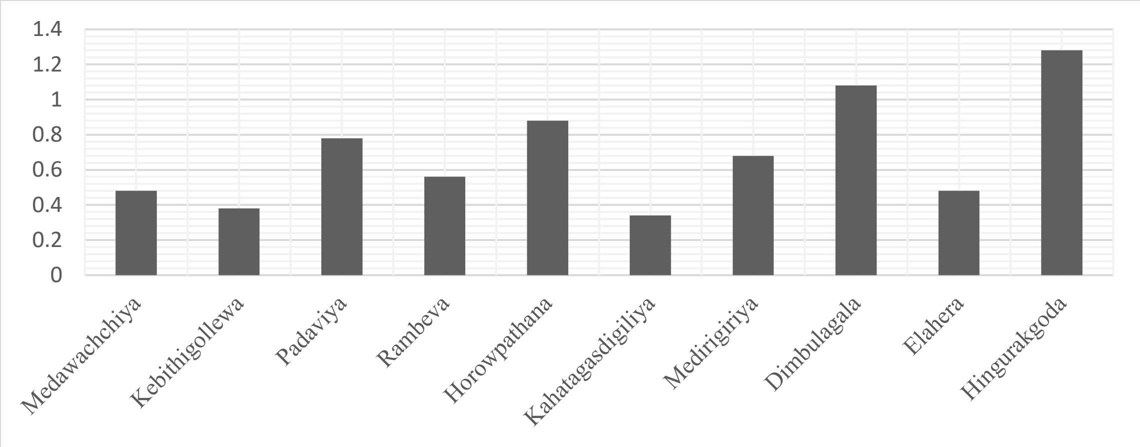


***Figure 4.7: Cadmium level of concentration in* µg/L**

**Lead (Pb)** concentrations measured between 5.64 µg/L and 8.66 µg/L across the sites. While below acute toxicity thresholds, chronic cumulative exposure to lead remains a concern for renal health, particularly among vulnerable populations in rural communities.

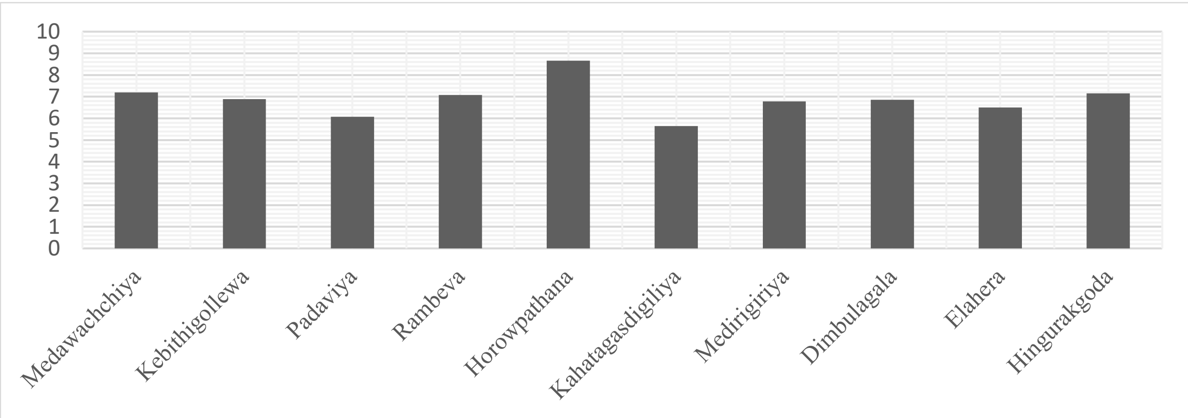


***Figure 4.8: Lead level of concentration in* µg/L**

### 4.3.2 Water Quality Index (WQI) Assessment

The Water Quality Index (WQI) was computed utilizing the measured physicochemical parameters to provide a comprehensive evaluation of water quality status across the study locations (Table 4.9).

***Table 4.9: WQI Values and Corresponding Water Quality Classifications Across Study Areas*.**

| Area | WQI | Interpretation |
|---|---|---|
| **Medawachchiya** | 108.12 | Poor |
| **Kebithigollewa** | 96.79 | Good |
| **Padaviya** | 127.46 | Poor |
| **Rambeva** | 111.61 | Poor |
| **Horowpathana** | 140.01 | Poor |
| **Kahatagasdigiliya** | 93.79 | Good |

| | | |
|---|---|---|
| **Medirigiriya** | 119.65 | Poor |
| **Dimbulagala** | 148.94 | Poor |
| **Elahera** | 100.43 | Poor |
| **Hingurakgoda** | 166.14 | Poor |

The WQI results categorized water quality as follows:

- **Good quality** water was observed in Kebithigollewa (WQI = 96.79) and Kahatagasdigiliya (WQI = 93.79).
- **Poor quality** water was recorded in the remaining eight sites, with the highest degree of deterioration found at Hingurakgoda (WQI = 166.14).

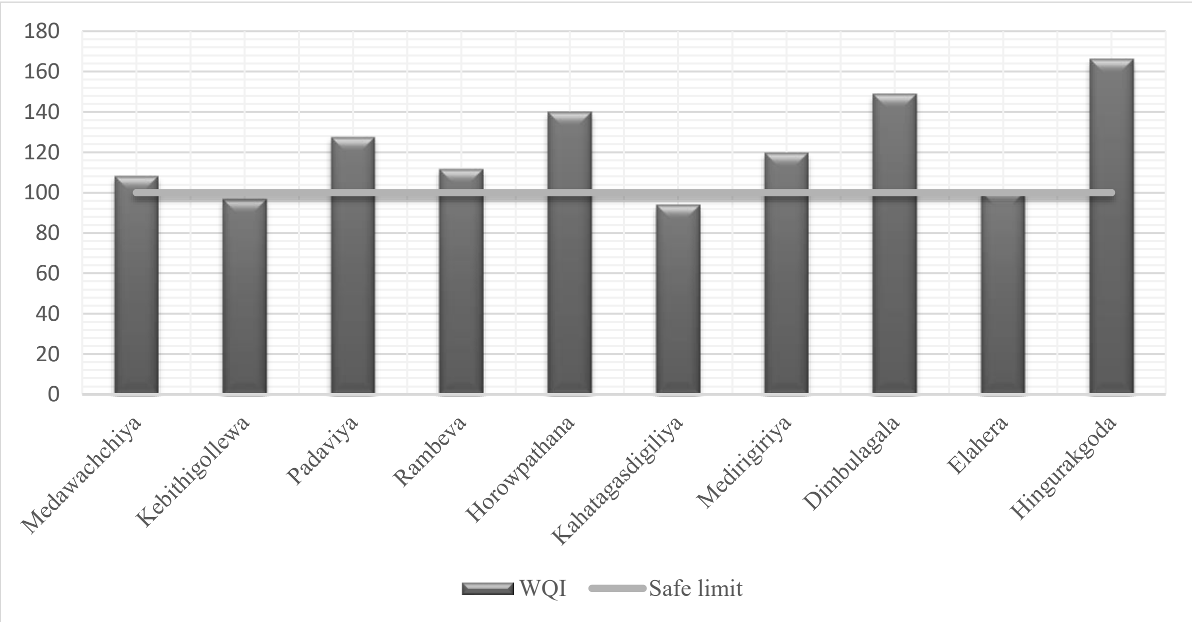


***Figure 4.9: WQI levels of CKDu hotspot area.***

The predominance of poor water quality aligns with the elevated concentrations of nitrates, heavy metals, and organic pollution indicators detected in these areas. These findings highlight significant water contamination concerns and underscore the urgent necessity for enhanced water resource management strategies and targeted public health interventions to mitigate potential adverse health outcomes in affected populations.

## 4.4 Soil Quality Assessment in CKDu Hotspot Areas

### 4.4.1 Concentration of Heavy Metals and Soil Contamination Indices

***Table 4.10: Presents the concentrations of cadmium (Cd), arsenic (As), and lead (Pb), alongside soil pH, contamination factors (Cf), and the Pollution Load Index (PLI) for each study site.***

| Location | Avg Cd (mg/kg) | Avg As (mg/kg) | Avg Pb (mg/kg) | pH | Cf(Cd) | Cf(As) | Cf(Pb) | PLI |
|---|---|---|---|---|---|---|---|---|
| **Medawachchiya** | **1.28** | **12.36** | **57** | **7.00** | **2.56** | **1.24** | **1.14** | **1.62** |
| **Kebithigollewa** | **1.60** | **9.10** | **48.8** | **6.70** | **3.20** | **0.91** | **0.98** | **1.66** |
| **Padaviya** | **1.80** | **16.24** | **66.4** | **6.60** | **3.60** | **1.62** | **1.33** | **2.09** |
| **Rambeva** | **1.14** | **11.70** | **57** | **7.08** | **2.28** | **1.17** | **1.14** | **1.50** |
| **Horowpathana** | **1.40** | **9.00** | **48.2** | **6.84** | **2.80** | **0.90** | **0.96** | **1.49** |
| **Kahatagasdigiliya** | **1.30** | **11.08** | **54.8** | **7.10** | **2.60** | **1.11** | **1.10** | **1.58** |
| **Medirigiriya** | **0.90** | **19.40** | **71.6** | **6.04** | **1.80** | **1.94** | **1.43** | **1.71** |
| **Dimbulagala** | **0.86** | **15.70** | **63.8** | **5.84** | **1.72** | **1.57** | **1.28** | **1.50** |
| **Elahera** | **1.14** | **22.76** | **81.6** | **5.64** | **2.28** | **2.28** | **1.63** | **2.06** |
| **Hingurakgoda** | **0.82** | **18.80** | **68.4** | **6.04** | **1.64** | **1.88** | **1.37** | **1.61** |

**Cadmium (Cd) Levels-** Cadmium concentrations in the study areas ranged from 0.82 to 1.80 mg/kg, remaining below the 3 mg/kg agricultural threshold but exceeding natural background levels (~0.5 mg/kg). These elevated levels are concerning due to cadmium's link to kidney damage, particularly affecting communities reliant on local agriculture.

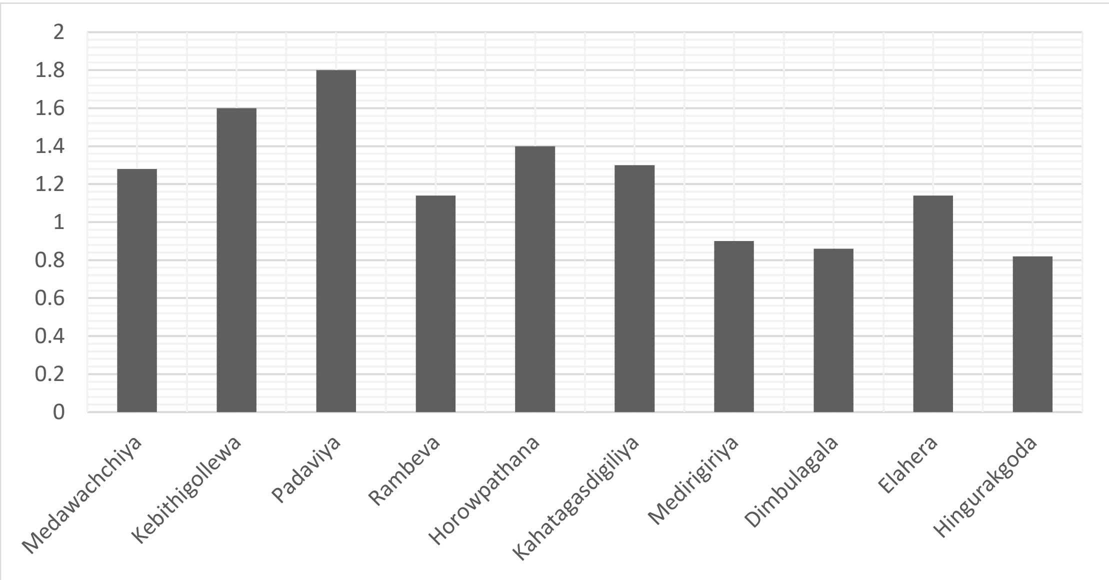


***Figure 4.10: Average cadmium level (mg/Kg) in each CKDu Hotspot***

**Arsenic (As) Levels-** Arsenic levels ranged up to 22.76 mg/kg in Elahera, exceeding the 20 mg/kg safety threshold, indicating possible anthropogenic contamination. Its persistence and potential for bioaccumulation through crops pose serious health risks, including renal damage.

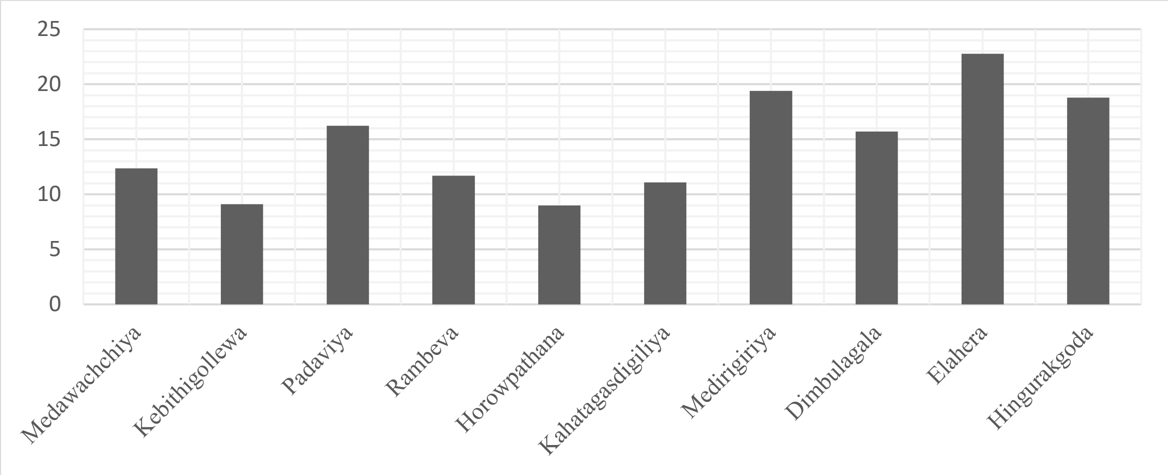


*Figure 4.11: Average Arsenic level (mg/kg) in each CKDu Hotspot*

**Lead (Pb) Levels-** Lead levels ranged from 48.2 to 81.6 mg/kg, exceeding preferred limits for sensitive land use. Though below the 100 mg/kg threshold, these concentrations suggest agricultural and atmospheric inputs, posing risks of oxidative stress and kidney damage.

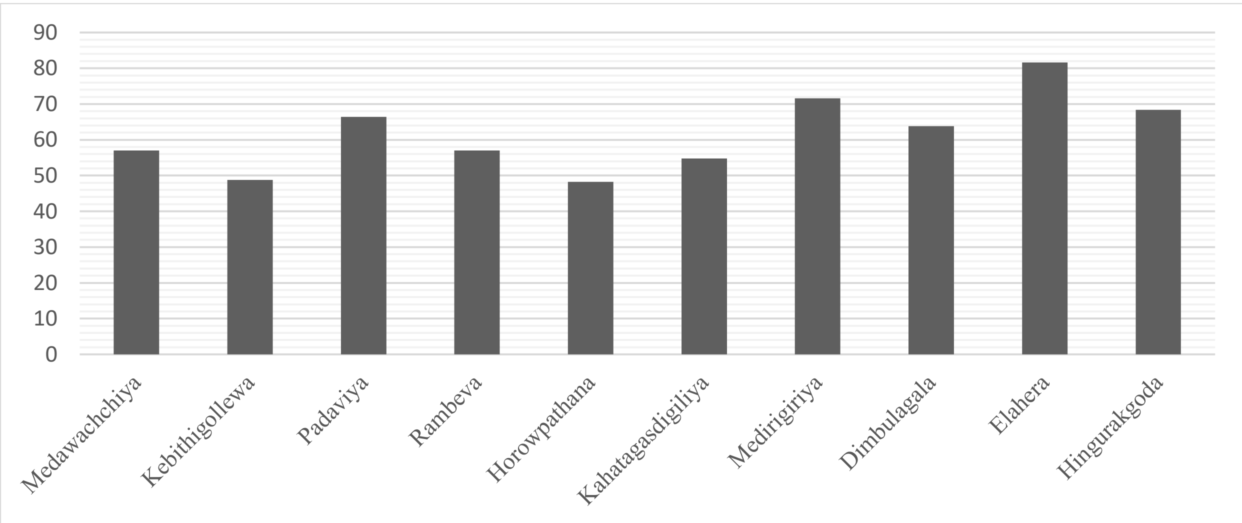


*Figure 4.12: Average Lead level (mg/kg) in each CKDu Hotspot*

## Soil pH and Implications for Metal Mobility

Soil pH across the sites ranged from moderately acidic (5.64 in Elahera) to neutral (7.10 in Kahatagasdigiliya). More acidic soils, particularly in Elahera and Dimbulagala, can enhance the solubility and mobility of heavy metals, increasing their bioavailability and potential for plant uptake and groundwater contamination.

## Contamination Factor (Cf) and Pollution Load Index (PLI)

Contamination factors (Cf) for cadmium were consistently above 1.5 across all sites, indicating moderate to considerable contamination. Sites such as Padaviya $Cf_{(Cd)}$ = 3.60) and

Kebithigollewa $Cf_{(Cd)}$ = 3.20) show especially high cadmium loading. Arsenic and lead contamination levels also reflect moderate risk, with Cf values generally exceeding 1.0.

The Pollution Load Index (PLI), an integrative measure of soil contamination, exceeded 1.5 in most areas, signifying widespread anthropogenic pollution. The highest PLI values were observed in Padaviya (2.09) and Elahera (2.06), both of which correspond with elevated heavy metal concentrations and lower pH, underscoring the need for urgent soil remediation strategies in these regions.

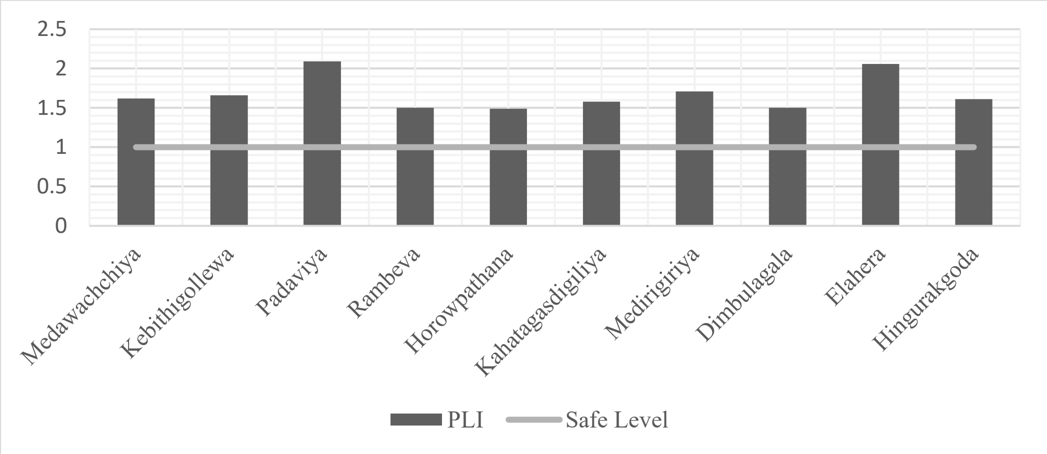


***Figure 4.13: Soil pollution load index in each CKDu hotspot***

### 4.5 Field Observations Across CKDu Hotspots

Field investigations across the ten study locations reveal consistent patterns of environmental risk factors aligned with CKDu prevalence, particularly related to groundwater quality, agricultural intensity, and socio-ecological conditions.

**Medawachchiya** demonstrates high CKDu prevalence among farming communities dependent on shallow wells containing elevated fluoride and hardness. Notably, the introduction of reverse osmosis (RO) systems has coincided with a visible decline in new CKDu cases, indicating a probable causal link between improved water quality and disease mitigation.

In **Kebithigollewa**, communities rely on mineral-rich groundwater, with chronic exposure to hardness and fluoride compounded by agrochemical use. Local interventions aimed at enhancing water safety are underway, though infrastructural limitations persist.

**Padaviya** is sustained by ancient irrigation networks, notably Padaviya Wewa, which support intensive paddy cultivation. Field evidence suggests that irrigation-derived fluoride exposure may contribute to CKDu among farming populations, necessitating integrated water governance.

**Rambeva** faces acute infrastructural deficits, with widespread use of untreated groundwater. Observations suggest potential contamination with nephrotoxic elements, underlining the urgency for safe water interventions.

**Horowpathana**, located near a protected forest area, exemplifies the overlap of ecological conservation and rural public health. Groundwater use and agricultural runoff present notable CKDu risk factors, warranting closer monitoring of human–environment interactions.

In **Kahatagasdigiliya**, reliance on tank and well water for paddy farming coincides with elevated fluoride levels. Community education and water treatment initiatives are emerging as key preventative strategies.

**Medirigiriya** is typified by widespread groundwater usage for both domestic and irrigation needs. Reports of excessive fluoride and hardness correlate with CKDu incidence, while RO installations offer promising early outcomes.

**Dimbulagala** relies on deep wells that may extract fluoride-rich water. The community's exposure risk is heightened by insufficient testing and limited access to purification technologies.

In **Elahera**, historical irrigation systems intersect with high groundwater fluoride levels, posing chronic nephrotoxic threats to the predominantly farming population. Sustained monitoring is essential to prevent further disease spread.

**Hingurakgoda**, a major agricultural zone in Polonnaruwa, exhibits some of the most contaminated groundwater profiles in the study. Field assessments reveal fluoride, hardness, and heavy metal exposure, reinforcing the critical need for scalable water safety programs.

## 4.6 Application of the NABC Model and Rogers' Diffusion of Innovation Theory for CKDu Mitigation

This section employs the **NABC framework** (Need, Approach, Benefit, Competition) to structure the policy solution, while leveraging **Rogers' Diffusion of Innovation Theory** to ensure the effective adoption and diffusion of key interventions at community level.

### 4.6.1 Strategic Food Policy Framing Using the NABC Model

**Need**

The prevalence of CKDu in Sri Lanka's dry zone farming communities is strongly associated with chronic exposure to nephrotoxic substances including cadmium, arsenic, and glyphosate—primarily transmitted through the consumption of contaminated water and food, as well as occupational exposure during agricultural activities. In addition, extreme heat exposure and dehydration among agricultural labourers significantly accelerate kidney damage. The crisis is exacerbated by a lack of enforceable environmental protection regulations, insufficient water safety infrastructure, limited food traceability systems, and low public awareness in rural areas. These gaps underline the urgent need for an integrated food policy framework that addresses environmental, occupational, and dietary risks collectively.

**Approach**

The proposed intervention adopts a **community-driven innovation model** that facilitates the adoption of sustainable agroecological practices and water safety measures. Key components include:

- **Agroecological Transition**: Promoting the shift from input-intensive monocultures to low-input, diverse farming systems rooted in organic and traditional knowledge. Demonstration plots are established in high-risk areas to encourage local experimentation and peer learning.

- **Geospatial Risk Zoning**: Application of GIS-based monitoring tools to identify High-Risk Cultivation Zones (HRCZs) based on soil and water quality indicators exceeding Codex Maximum Residue Limits (MRLs) for nephrotoxic elements.
- **Food Traceability Systems**: Implementation of digital platforms (e.g., QR-code or blockchain-based systems) that enhance transparency and allow consumers to trace the source, safety, and handling of food products.
- **Water Safety Infrastructure**: Deployment of low-cost, point-of-use water purification systems such as reverse osmosis (RO) filters in schools, hospitals, and households in endemic areas.
- **Capacity Building**: Training agricultural officers, health workers, and community leaders to act as facilitators of behaviour change, using participatory methods aligned with cultural and economic contexts.
- **District-Level Food Policy Councils**: Establishment of decentralized, multi-sectoral governance platforms to coordinate interventions across health, agriculture, environment, and community development sectors.

**Benefit**

The integrated approach yields multiple co-benefits:

- **Health Benefits**: Reduction in CKDu incidence, improved public health literacy, and earlier detection of at-risk individuals.
- **Economic Resilience**: Decreased healthcare costs and enhanced livelihood security through agroecological diversification and access to premium markets for certified produce.
- **Environmental Sustainability**: Restoration of soil health, reduction of heavy metal accumulation, and preservation of local biodiversity.
- **Governance Innovation**: Enhanced policy coherence and local empowerment through participatory governance structures aligned with FAO’s agroecology evaluation tools.

**Competition / Alternatives**

Existing interventions for CKDu are often fragmented, predominantly clinical, and lack contextual grounding. These include:

- **Medical-Only Interventions**: Dialysis and transplantation services that treat the outcome but not the causes.
- **Regulatory Bans**: Partial or poorly enforced bans on agrochemicals, which are insufficient due to lobbying pressure and weak monitoring.
- **Top-Down Policies**: Centralized interventions with limited stakeholder engagement, resulting in low community ownership.

In contrast, the proposed model integrates scientific evidence, local knowledge, and institutional partnerships to provide a participatory, preventive, and scalable solution.

### 4.6.2 Adoption Strategy Using Rogers’ Diffusion of Innovation Theory

Rogers’ theory provides a framework for understanding how new practices are adopted in communities, especially in contexts marked by resource constraints, cultural diversity, and environmental risk. The five key attributes of innovation—**relative advantage, compatibility, complexity, trialability, and observability**—are strategically applied to enhance community uptak

*Table 4.11: Application of Rogers' Five Innovation Attributes in CKDu Mitigation Strategies*

| Attribute | Application in CKDu Mitigation |
|---|---|
| **Relative Advantage** | Organic farming and water purification offer clear health and financial benefits to communities. |
| **Compatibility** | Innovations are designed to align with traditional rice cultivation and dietary habits. |
| **Complexity** | Field demonstrations and simplified training reduce perceived technical difficulty. |
| **Trialability** | Pilot projects and demonstration farms allow safe experimentation by farmers and households. |
| **Observability** | Improvements in water quality and health outcomes are visible and reinforce adoption. |

**Adopter Categories and Stakeholder Roles**

*Table 4.12 – Adopter Categories and Stakeholder Roles in CKDu Mitigation Innovation Diffusion*

| Adopter Category | Key Stakeholders | Role in CKDu Mitigation |
|---|---|---|
| **Innovators** | Universities, research institutions, NGOs | Pilot agroecological farming, traceability tools, and GIS-based zoning technologies |
| **Early Adopters** | Influential farmers, local input dealers, district-level health officers | Trial sustainable practices early, advocate for innovation within communities |
| **Early Majority** | Farmer cooperatives, community-based organizations | Adopt innovations based on observed benefits and peer endorsement |
| **Late Majority** | Risk-averse smallholders, financially constrained producers | Respond to incentives, subsidies, and policy enforcement pressures |
| **Laggards** | Elderly or traditionalist farmers, low-resource households | Require targeted awareness campaigns, regulatory mandates, and sustained support to change |

**Communication Channels and Change Agents**

Effective communication strategies are essential for innovation diffusion. These include:

- **Interpersonal Channels**: Farmer field schools, women's groups, and village assemblies.
- **Mass Media**: Community radio, TV documentaries, posters, and SMS alerts tailored to rural audiences.
- **Extension Networks**: Agricultural extension officers and community health workers trained as trusted intermediaries.
- **Digital Platforms**: Mobile dashboards for environmental data, QR codes for product traceability, and digital learning tools.

**Diffusion of Innovation Timeline for CKDu Mitigation**

*Table 4.13 – Diffusion of Innovation Timeline for CKDu Mitigation Aligned with Food Policy Implementation Phases*

| Year | Diffusion Activities (Aligned with Rogers' Theory) |
|---|---|
| **Year 1** | - **Awareness Generation**: Launch mass media campaigns, community meetings, and interpersonal outreach on CKDu risks and agroecological solutions. - **Environmental Risk Zoning**: Identify High-Risk Cultivation Zones (HRCZs) using GIS mapping and soil/water testing. - **Engagement of Innovators**: Collaborate with researchers, NGOs, and universities to pilot policy tools and technologies. |
| **Year 2** | - **Early Adoption Support**: Deploy agroecological pilots in 5 GN divisions to engage early adopters like progressive farmers and health officers. - **Traceability System Initiation**: Launch blockchain-based food traceability networks in pilot areas. - **Water Infrastructure Rollout**: Begin installation of reverse osmosis units in schools and homes in targeted areas. - **Capacity Building**: Conduct farmer field schools, extension training, and village-level demonstrations. |
| **Year 3** | - **Expansion to Early Majority**: Showcase observable results (improved yields, lower illness rates) to engage the early majority. - **Institutionalization of FPCs**: Operationalize Food Policy Councils (FPCs) across districts for cross-sectoral governance. - **Monitoring Systems**: Implement SQI/WQI dashboards and QR-code-based monitoring for food and water quality. |
| **Year 4** | - **Late Majority Adoption**: Use evidence from prior years to influence conservative or risk-averse farmers through peer pressure and policy incentives. - **Scaling of Interventions**: Expand agroecological and traceability systems to new regions based on feedback and results. |
| **Year 5** | - **Laggard Engagement**: Reach lagging adopters through enforced regulation, targeted subsidies, and support services. - **Policy Harmonization**: Integrate findings into national food and environmental policy frameworks. - **Sustainability Measures**: Embed innovation practices into long-term community norms and institutional systems. |

## 4.7 Agroecological Sustainability Assessment Using FAO TAPE

This study applied TAPE to assess eight key dimensions Diversity, Synergies, Efficiency, Recycling, Resilience, Culture and Food Traditions, Responsible Governance, and Circular & Solidarity Economy in selected CKDu-endemic divisions in the North Central Province of Sri Lanka.

**Diversity Assessment:**
Biodiversity underpins ecological resilience and the long-term productivity of agroecosystems (Altieri, 1999). However, in the studied regions such as Padaviya and Medawachchiya, the dominance of paddy monocultures limits both species and genetic diversity. Field surveys and stakeholder interviews revealed a lack of crop diversification, minimal intercropping, and negligible agroforestry practices. Heavy metal contamination in soils—particularly elevated cadmium and arsenic levels—further compromises plant diversity by degrading soil microbiota

and reducing the viability of alternative crops (Jayasumana et al., 2015; Bandara et al., 2010). Traditional drought-resilient and nutrient-dense crop varieties have been largely displaced by high-yield but input-intensive rice varieties.
**Score:** 2/5
Low crop diversity and environmental stressors indicate poor agroecosystem heterogeneity. Targeted crop diversification strategies and traditional seed preservation efforts could improve biodiversity.

**Synergies Assessment:**
Synergies arise from integrating biological interactions, such as those between crops, livestock, and natural ecosystems, to optimize productivity and ecosystem services (Tittonell, 2020). This study identified minimal interaction between water management, pest control, and soil fertility strategies. Agrochemical use remains high, and biological pest control or soil microbial enhancement strategies are rarely practiced. In Medirigiriya and Rambeva, some community-level integration was observed, such as aligning reverse osmosis (RO) water systems with safe irrigation practices—demonstrating potential for ecological-health synergies.
**Score:** 2/5
Despite isolated examples of synergistic practice, system-wide implementation remains limited.

**Efficiency Assessment:**
Agroecological efficiency focuses on maximizing resource productivity and minimizing losses. Inefficiencies in irrigation, energy use, and nutrient cycling were prominent in Padaviya and Kebithigollewa. Over-application of synthetic fertilizers and poor irrigation design contribute to runoff, leaching, and groundwater contamination with cadmium, arsenic, and fluoride (Panabokke et al., 2017). Dependence on costly chemical inputs exacerbates ecological and economic inefficiencies.
**Score:** 2/5
There is a critical need to improve irrigation scheduling and adopt integrated nutrient management to optimize resource efficiency.

**Recycling Assessment:**
Recycling in agroecology involves reintegrating organic matter into the production cycle to close nutrient loops. However, in the study regions, crop residues and animal waste are underutilized. Plastic agrochemical waste is frequently discarded in open fields or water sources. Organic composting initiatives are rare, with only small-scale efforts seen in Dimbulagala. FAO recommends recycling as a key strategy to minimize external inputs and reduce environmental footprints (FAO, 2019).
**Score:** 2/5
Limited recycling practices undermine nutrient cycling and contribute to pollution.

**Resilience Assessment:**
Agroecosystem resilience is vital in adapting to climatic and economic stressors. Field data indicate widespread environmental vulnerability, particularly in regions affected by drought and soil degradation. Heavy reliance on chemical inputs and monocultures reduces adaptive capacity to climate extremes and pest outbreaks. Climate-smart strategies, such as drought-resistant crops and water-efficient irrigation, are virtually absent (Wickramasinghe et al., 2022).

**Score:**1.5/5
This low score reflects high vulnerability to climate, economic, and ecological shocks.

**Culture and Food Traditions Assessment:**
Local food systems remain embedded in cultural heritage. Traditional dishes and rice varieties are still valued. However, health risks associated with contaminated water and food (e.g., through fluoride accumulation) undermine food safety. Nutritional diversity is compromised by the narrowing of crop choices and reliance on rice-based diets (Wasana et al., 2015). There is also a disconnect between traditional knowledge and current farming practices, exacerbated by declining youth participation in farming.
**Score:**3/5
Cultural integrity remains, but contamination and monocropping reduce nutritional and health value.

**Responsible Governance Assessment:**
Effective governance is essential for agroecological transition. While the Sri Lankan government recognizes CKDu as a public health crisis, institutional enforcement of agrochemical regulation and water safety standards is weak (Senanayake et al., 2021). Local councils lack capacity to enforce guidelines on land use, irrigation, and chemical inputs. Community governance mechanisms in Kebithigollewa show potential but require national policy support and capacity-building.
**Score:** 2/5
Inadequate enforcement and institutional fragmentation hinder sustainable governance.

**Circular & Solidarity Economy Assessment:**
This dimension assesses the reuse of resources and equitable benefit sharing. Agricultural economies in the study areas are highly linear, with a dependence on imported agrochemicals and limited reinvestment in local value chains. Income inequality among farmers—particularly between large and smallholders—is evident. Nonetheless, emerging community-led initiatives (e.g., cooperative RO plants in Rambeva) show early signs of solidarity-based economic models.
**Score:** 2/5
Broader adoption of cooperative models and circular farming practices is needed to build socio-economic resilience.

***Table 4.14 Summary Table: Agroecological Sustainability Scores***

| TAPE Element | Score | Justification |
|---|---|---|
| **Diversity** | 2 | Dominance of monoculture and heavy metal contamination limiting biodiversity. |
| **Synergies** | 2 | Weak coordination between water, soil, and pest management systems. |
| **Efficiency** | 2 | Low water and nutrient use efficiency; overuse of agrochemicals. |
| **Recycling** | 2 | Poor organic waste recycling and lack of composting systems. |
| **Resilience** | 1.5 | High climate vulnerability and ecological degradation. |
| **Culture and Food Traditions** | 3 | Cultural value remains, but dietary diversity and safety are compromised. |

| | | |
|---|---|---|
| **Responsible Governance** | 2 | Weak enforcement of environmental policies and fragmented institutional response. |
| **Circular & Solidarity Economy** | 2 | Limited resource reuse and unequal economic participation. |

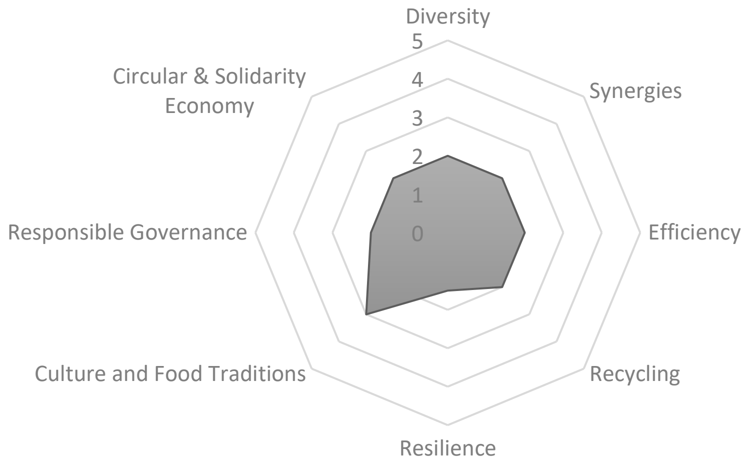


***Figure 4.14: Radar Graph of Sustainability Scores Across TAPE Dimensions***

### Policy Integration with FAO Guidelines

Findings reveal significant deviations from FAO's recommended practices for sustainable soil and irrigation management. For instance, the FAO sets a threshold for cadmium in soils at 0.5 mg/kg, and emphasizes the importance of managing soil pH to limit heavy metal mobilization (FAO, 2021). In this study, acidic soils and cadmium concentrations above 1.0 mg/kg were recorded in Elahera and Dimbulagala—conditions that heighten bioavailability of nephrotoxic substances. Furthermore, input-intensive monoculture systems remain entrenched despite FAO's call for diversified, agroecological systems with closed nutrient loops and inclusive governance (FAO, 2019; Gliessman, 2015). The lack of integrated nutrient management and water safety regulation signals a low agroecological maturity level and necessitates urgent policy realignment.

5. **Results and Strategic Food Policy:**
   **Evidence-Based Food Policy Framework for CKDu Mitigation**

## 5.1 Integrated Food Policy Framework for CKDu Mitigation in Sri Lanka

The primary objective of this integrated food policy is to strategically reduce the incidence and progression of Chronic Kidney Disease of unknown etiology (CKDu) in Sri Lanka by incorporating agroecological principles, environmental health sciences, and spatial food governance within the national food system. This multifaceted approach will be operationalized through the application of advanced technological tools for risk-based zoning, strict enforcement of toxicological thresholds across agricultural products and environmental compartments, and the promotion of sustainable agronomic transitions in CKDu-endemic regions of Anuradhapura and Polonnaruwa districts.
The policy is designed with the following specific aims:

1. **Mitigation of Nephrotoxic Exposure Pathways:**
Targeting primary exposure routes—including contaminated water, soil, and food crops—through the rigorous enforcement of Maximum Residue Limits (MRLs) for agrochemicals, coupled with enhanced soil and water remediation strategies to reduce nephrotoxic burdens in affected environments.
2. **Promotion of Sustainable Agroecological Practices:**
Facilitating the adoption of low-input, circular agricultural systems guided by the Food and Agriculture Organization's (FAO) Tool for Agroecology Performance Evaluation (TAPE). This approach seeks to minimize environmental toxicant load, bolster ecosystem resilience, and secure safe, nutritious diets for vulnerable populations.
3. **Establishment of Multi-Scalar Food Governance Mechanisms:**
Creating an integrative governance framework that links district-level Food Policy Councils (FPCs) with national regulatory institutions. This structure aims to enable participatory, evidence-based decision-making processes that holistically address food safety, environmental health, and CKDu prevention.

## 5.2 Scientific Justification and Technical Mechanisms

### 5.2.1 Targeted Risk Mitigation through Environmental Surveillance and Geospatial Zoning

Utilizing comprehensive geostatistical analyses of nephrotoxic contaminants including cadmium (Cd), arsenic (As), lead (Pb), fluoride, and related elements derived from systematic field sampling across CKDu-endemic hotspots, this policy framework delineates designated **High-Risk Cultivation Zones (HRCZs)**. Within these zones, rigorous, geo-referenced environmental monitoring protocols will be mandated. To ensure early detection of nephrotoxic elements and enable targeted intervention, a dual approach of high-resolution environmental surveillance and ecological remediation will be employed. The core activities, techniques, and intended outcomes are detailed in Table 5.1

*Table 5.1: Environmental Monitoring and Soil Remediation Strategy*

| Component | Activity | Technical Method | Expected Outcome |
|---|---|---|---|
| Water Quality Monitoring | Periodic testing of irrigation and domestic wells | ICP-MS for heavy metals and fluoride; field kits for pH and EC | Early detection of nephrotoxins; risk zoning of contaminated aquifers |
| Soil Contaminant Surveillance | Scheduled sampling of agricultural soils | X-Ray Fluorescence (XRF) and ICP-MS | Multi-element profiling; spatial-temporal maps of heavy metal concentrations |
| Phytoremediation | Cultivation of hyperaccumulator plant species (e.g., Brassica juncea) | Site-specific planting based on contaminant profile | In situ reduction of Cd and As levels in soil; biomass disposal post-harvest |
| Soil pH Adjustment | Application of lime to acidic soils (pH < 6.5) | pH testing and lime requirement calculation | Decreased metal solubility and mobility; improved soil fertility |

### 5.2.2 Agroecological Transition to Mitigate Input-Derived Toxicity

Monoculture-dependent agricultural systems in CKDu-affected regions have led to ecological imbalances and excessive reliance on synthetic inputs, as revealed by FAO-TAPE assessments. An agroecological transition is thus essential to restore ecosystem functionality, reduce nephrotoxic bioaccumulation, and enhance food system sustainability. Table 5.2 outlines the key intervention components.

*Table 5.2: Agroecological Transition Strategies for Reducing Input-Derived Toxicity*

| Intervention Area | Key Activity | Technical/Policy Mechanism | Expected Outcome |
|---|---|---|---|
| **Soil Fertility Rehabilitation** | Capacity building in Integrated Nutrient Management (INM) | Farmer training on composting, green manuring, microbial biofertilizers | Reduced dependence on synthetic fertilizers; improved soil microbial health |
| **Agrobiodiversity Enhancement** | Crop diversification through rotations, polycultures, and agroforestry | Incentive schemes for seed access, subsidies, and extension support | Enhanced ecological synergy; decreased contaminant accumulation in food crops |

| | | | |
|---|---|---|---|
| **Reduced Exposure Pathways** | Adoption of Controlled Environment Agriculture (CEA) in high-risk areas | Deployment of net-housesand hydroponics in contaminated zones | Physical separation from toxic soils; safer production of leafy greens and vegetables |

These strategies collectively foster agroecological resilience, reduce toxic exposure pathways, and contribute to a long-term reduction in CKDu-associated dietary risks.

### 5.2.3 Food Chain Traceability and Toxicological Safeguards

To prevent the ingress of nephrotoxin-contaminated produce into consumer markets, the policy introduces a comprehensive national agri-food traceability system supported by advanced technologies. Figure 5.1 illustrates the integrated workflow.

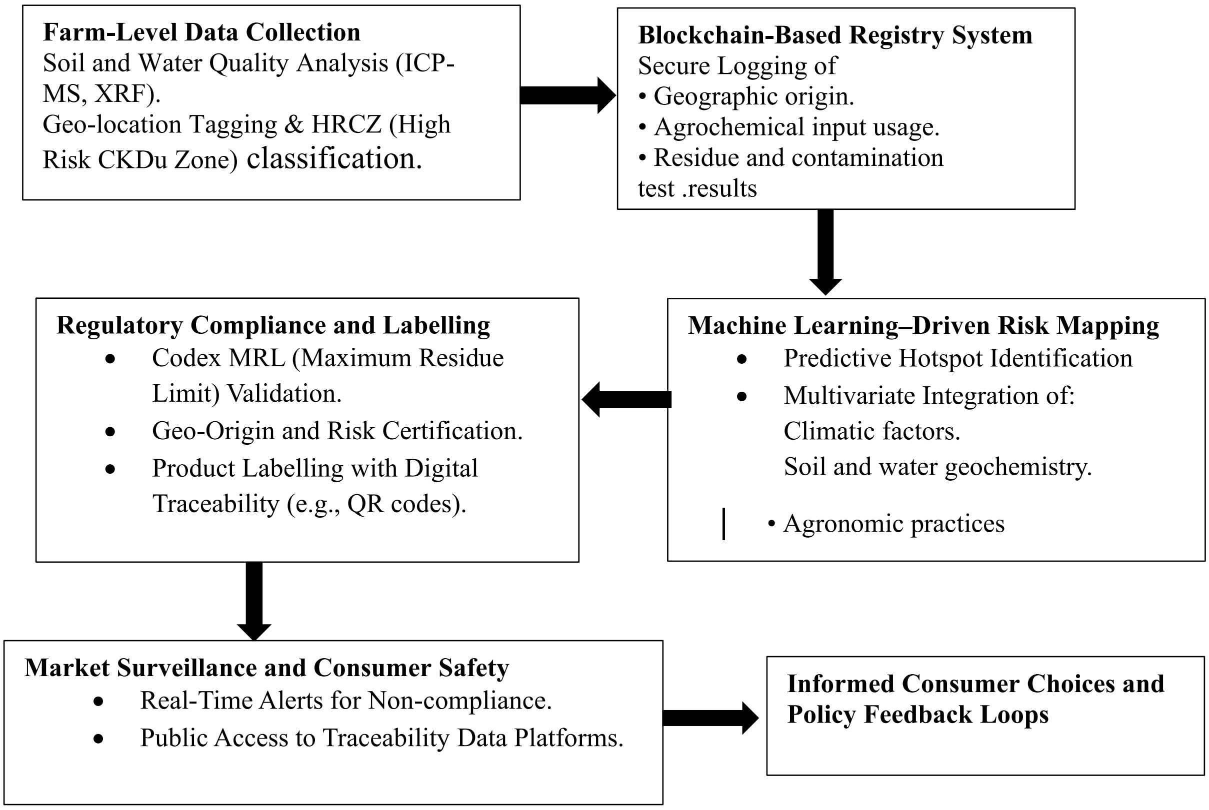


***Figure 5.1: Workflow of the National Agri-Food Traceability and Safety System***

This traceability framework ensures transparency across the supply chain, enabling both regulatory enforcement and consumer confidence. By integrating real-time contaminant data with AI-driven risk mapping, the system facilitates proactive food safety governance and minimizes CKDu-related dietary exposure

### 5.2.4 Water Safety Enhancement through Community Centric Purification Infrastructure.

Given the critical reliance on groundwater in CKDu-endemic regions, the proposed food policy emphasizes decentralized, community-managed water safety measures. It recommends widespread adoption of point-of-use purification technologies—such as reverse osmosis, activated alumina, and nanofiltration—in rural households and schools to remove nephrotoxic contaminants like heavy metals and fluoride.

To ensure ongoing monitoring, the policy supports expanding community-based water quality surveillance using portable test kits and remote sensing, coordinated by district-level Food Policy Councils (FPCs). Additionally, it promotes ecological interventions such as rainwater harvesting and managed aquifer recharge (MAR) to dilute contaminant concentrations in shallow aquifers. Collectively, these measures aim to improve water safety through participatory, sustainable strategies.

### 5.2.5 Socio-Ecological Capacity Building and Public Education

Acknowledging the pivotal role of community practices in modulating environmental exposures, this policy prioritizes:

- The establishment of localized agroecology training centers delivering landscape-specific technical education encompassing soil pH adjustment, biochar application, and sustainable farming practices.
- Utilization of participatory rural appraisal (PRA) methodologies and risk communication frameworks to enhance public awareness regarding dietary nephrotoxins, safe water usage, and low-input agriculture.
- Collaboration with universities and vocational institutions to integrate food landscape literacy into formal curricula for farming communities, fostering long-term behavioral change and resilience.

### 5.2.6 Institutional Mechanism: District-Level Food Policy Councils (FPCs)

***Table 5.3: Governance Functions of District-Level Food Policy Councils (FPCs)***

| Governance Function of FPCs | Description |
|---|---|
| Intersectoral Coordination | Aligns health, agriculture, and environment sector policies and facilitates integrated nephrotoxin monitoring. |
| Project Oversight and Transparency | Supervises soil remediation efforts, administers input subsidies, and ensures public access to contamination data. |
| Public–Private Partnerships (PPP) | Encourages collaboration for upscaling sustainable technologies and supporting agroecological entrepreneurship. |

**Expected Outcomes of FPC Implementation**

*Table 5.4: Expected Outcomes of Integrated Food Policy Governance via FPCs*

| Impact Area | Anticipated Outcome |
|---|---|
| Nephrotoxin Exposure Reduction | Lower dietary and hydrological exposure to nephrotoxic elements in CKDu-prone districts. |
| Environmental Quality Improvement | Enhanced soil, water, and crop health via ecological intensification and targeted remediation practices. |
| Livelihood Resilience | Improved rural sustainability and economic security through environmentally responsible farming systems. |
| Scalability and Replicability | Creation of a governance model adaptable to other regions facing complex environmental health challenges. |

### 5.3 Policy Pillars and Scientific Justification

#### 5.3.1 Pillar 1: Spatial Risk-Based Food Production Zoning

**Policy Action:**
This pillar proposes the designation of High-Risk Cultivation Zones (HRCZs) based on geospatial analytics and integrated environmental health indices. These indices are developed using GIS-linked multi-parameter datasets encompassing:

- Heavy metal concentrations (e.g., Cadmium [Cd], Arsenic [As], Lead [Pb])
- Soil pH (acid-base balance influencing metal solubility)
- Total hardness ($Ca^{2+}$, $Mg^{2+}$ content)
- Fluoride ($F^{-}$) levels

Within HRCZs:

- Cultivation of nephrotoxin-accumulating crops—such as rice (Oryza sativa), leafy vegetables (Amaranthus spp., Ipomoea spp.), and certain culinary herbs—will be restricted.
- Pre-harvest contaminant screening will be mandated using inductively coupled plasma mass spectrometry (ICP-MS) and atomic absorption spectroscopy (AAS).
- The cultivation of low-uptake crops (e.g., cassava, sweet potato), nitrogen-fixing legumes, and non-edible phytoremediative species such as Vetiver (Chrysopogon zizanioides) will be encouraged.

**Scientific Justification:**
Field data confirm elevated cadmium (Cd >0.4 mg/kg) and arsenic (As >0.2 mg/kg) concentrations in acidic soils (pH <6.5), which significantly enhance the solubility and bioavailability of these nephrotoxicants. Under such conditions, the uptake of toxic metals by staple crops like rice increases, posing heightened risks to food safety and public health. Spatial zoning based on geospatial risk indices enables a precision agriculture policy approach, allowing regulatory and agronomic interventions to be focused where the risk-to-yield trade-off is highest. This targeted strategy improves the efficiency of soil remediation, contaminant

monitoring, and crop substitution programs, thereby reducing chronic exposure pathways while preserving agricultural productivity.

### 5.3.2 Pillar 2: CKDu-Safe Farming through Agroecological Intensification

**Policy Action:**
Agroecological transition packages will be deployed in CKDu-prevalent Grama Niladhari (GN) divisions to include:

- Diversification with stress-tolerant and low-metal-uptake crops such as millets, indigenous legumes, and medicinal herbs (e.g., Phyllanthus spp., Withania somnifera).
- Soil health regeneration via compost, nitrogen-fixing cover crops (Mucuna, Sesbania), and microbial biofertilizers (Azospirillum, Phosphobacteria).
- Integrated water management practices like alternate wetting and drying (AWD) and micro-catchments.
- Soil pH correction using lime ($CaCO_3$, dolomite) to immobilize heavy metals.

**Technology Integration:**

- Bluetooth-enabled soil pH sensors for guided liming.
- AI-based agroecology advisory apps.
- IoT-based fertigation systems for efficient nutrient management.

**Scientific Justification:**
Agroecological methods improve cation exchange capacity and organic matter content, reducing bioavailability of toxicants (Alloway, 2013). The FAO's TAPE framework (2020) emphasizes agroecology's potential to regenerate ecosystem services vital for CKDu resilience.

### 5.3.3 Pillar 3: Food Chain Traceability and Safety Governance

**Policy Action:**
A national CKDu Food Traceability Network (CFTN) will be established featuring:

- Geotagged cultivation plots linked to soil and water toxicity data.
- Digital crop passports including agrochemical usage and toxicology results.
- CKDu-risk labeling for products from HRCZs.
- Enforcement of Codex Alimentarius Maximum Residue Limits (MRLs) (e.g., 0.2 mg/kg Cd in cereals).

**Scientific Justification:**
Chronic exposure to nephrotoxins via contaminated food is a principal CKDu pathway. Blockchain-based traceability and QR 57abelling enhance transparency, enabling targeted recalls and informed consumer choices. This aligns with Hazard Analysis and Critical Control Points (HACCP) principles and strengthens environmental health risk communication.

### 5.3.4 Pillar 4: Community-Scale Water Safety Infrastructure

**Policy Action:**
To address nephrotoxic co-contamination in groundwater:

- Install solar-powered sand filtration and reverse osmosis (RO) units in HRCZs.
- Mandate annual testing for Cd, As, and $F^-$, with results published via GN-level dashboards.
- Establish youth-led Clean Water Watch programs using field kits and mobile reporting tools.

**Scientific Justification:**
Research highlights the synergistic nephrotoxicity of $F^-$, Cd, and As in hard water, leading to proximal tubule damage and oxidative stress (Flaten, 2001; Jayasumana et al., 2015). RO and nanofiltration systems effectively reduce such exposures. Community-based monitoring fosters long-term sustainability and behavioral change.

### 5.3.5 Pillar 5: Local Governance through Food Policy Councils (FPCs)

**Policy Action:**
District-level FPCs will be constituted with representatives from:

- Farmer organizations
- Public health services
- Soil and water science experts
- Local policymakers

Core responsibilities:

- Auditing agrochemical usage
- Coordinating soil and water remediation projects
- Leading public education campaigns on CKDu-safe practices

**Scientific Justification:**
Polycentric governance fosters landscape-sensitive solutions and enhances policy responsiveness. Drawing from models like the Toronto and Brighton Food Policy Councils, this approach embeds environmental governance in community structures and enables real-time policy feedback loops. Incorporation of Traditional Ecological Knowledge (TEK) ensures cultural relevance and knowledge co-creation.

## 5.4 Monitoring and Evaluation Framework

To validate outcomes and ensure adaptive governance, this framework integrates FAO-recognized tools (CRFS, TAPE), digital surveillance, and citizen science methodologies.

**A. Agroecological Performance Monitoring**

Using FAO's Tool for Agroecology Performance Evaluation (TAPE), eight sustainability dimensions will be assessed annually:

1. Natural Resource Governance
2. Economic Resilience
3. Biodiversity & Ecosystem Services
4. Innovation & Co-creation
5. Farmer Empowerment
6. Social Equity
7. Nutrition & Food Security
8. Climate & Market Resilience

**Key Indicators:**

- Soil Organic Carbon (SOC)
- Agrochemical substitution rate
- Crop diversity and intercropping frequency
- Market access for agroecological produce

**Data Collection Tools:**

- Digital farm surveys
- Spectral soil analysis
- Remote sensing (e.g., NDVI)

**B. Contaminant Load Surveillance**

**Methodology:**

- Biannual sampling of crops (rice, greens, herbs) for Cd, As, and $F^-$ via ICP-MS.
- Soil and water grids tested pH, CEC, EC, and nephrotoxic elements.
- Data visualized through CRFS-integrated dashboards.

**Functions:**

- Hotspot identification
- Multi-sectoral alerts
- Longitudinal trend analytics with AI anomaly detection

**C. Governance and Resilience Metrics**

Using modified Social Network Analysis (SNA) and FAO-RIMA II:

- Participation density in FPCs and Clean Water Watch
- Policy feedback responsiveness
- Household-level resilience scores (food diversity, water safety, CKDu-related health expenses)

**Digital Tools:**

- **TAPE Dashboard App**: For real-time geotagged data entry by field officers.
- **CRFS Data Portal**: Integrates Earth Observation data with GN-level environmental layers for public and policy access.

## 5.5. Implementation Roadmap

The multi-phase roadmap is structured for **evidence-driven rollout**, with pilot feedback loops embedded for iterative refinement.

***Table 5.5: Multi Phase of Implementation of Food Policy***

| Phase | Action | Details | Timeline |
|---|---|---|---|
| **Phase 1** | Environmental Zoning & Contamination Mapping | Generate risk-tiered cultivation maps using GIS overlay of soil and water contaminant levels; initiate baseline CKDu exposure surveys and multi-temporal satellite imaging for land use. | Year 1 |
| **Phase 2** | Agroecological Transition Pilots in 5 GN Divisions | Implement full TAPE-based packages, including biofertilizers, lime applications, diversified cropping, and AI advisory apps. Monitor agronomic, ecological, and toxicological indicators quarterly. | Years 1–2 |
| **Phase 3** | Traceability Registry & Labeling Protocols | Develop and test Digital Crop Passport (DCP) system, with QR-based CKDu-risk labeling. Train farmer cooperatives and FPCs to manage inputs. Enact MRL compliance testing protocol in key food markets. | Year 2 |
| **Phase 4** | FPC Establishment & Community Water Programs | Set up District FPCs and launch Clean Water Watch youth brigades. Install solar filtration units and conduct participatory water quality training. Begin annual well testing registry. | Years 2–3 |
| **Phase 5** | Monitoring, Upscaling, & National Integration | Use monitoring results to scale up policy to 20+ GN divisions, refine zoning maps, and prepare national adoption plan via Ministry of Agriculture & Health joint task force. | Years 3–5 |

## 5.6 Expected Outcomes

The proposed policy framework is anticipated to deliver multifaceted improvements across environmental, agricultural, dietary, and governance domains. These outcomes are grounded in quantitative metrics and internationally recognized evaluation tools, ensuring accountability and replicability.

### A. Reduction in Nephrotoxin Contaminants

A primary outcome is the substantial reduction in cadmium (Cd), arsenic (As), and fluoride ($F^-$) concentrations in food crops sourced from High-Risk Cultivation Zones (HRCZs). A targeted ≥50% reduction is projected, verified through pre- and post-intervention inductively coupled plasma mass spectrometry (ICP-MS) datasets, with matched seasonal and geographic controls. Specific contaminant reductions include:

- Cd: from ~0.4 mg/kg to <0.2 mg/kg in rice.
- As: from ~0.2 mg/kg to <0.1 mg/kg in leafy vegetables.

These reductions aim to minimize chronic dietary exposure pathways that contribute to CKDu risk.

### B. Agroecological Sustainability Metrics (FAO-TAPE)

Utilizing the FAO's Tool for Agroecology Performance Evaluation (TAPE), the intervention targets an average increase of three points across the eight core agroecological dimensions. Expected gains include:

**Soil Health**: A 2% increase in soil organic carbon, indicating improved nutrient cycling and soil fertility.

**Biodiversity**: A doubling of crop species count per hectare, enhancing agroecosystem resilience.

**Pesticide Use**: At least a 60% reduction in the application of synthetic chemical inputs, contributing to ecological balance and reduced toxic load.

### C. Enhanced Dietary and Food System Resilience

Food and nutrition security are projected to improve through diversified cropping and local food system strengthening:

- **Household Dietary Diversity Score (HDDS)**: An increase from a baseline of 4.5 to ≥6.5.
- **Market Penetration of Safe Crops**: By Year 5, 30% of local food market produce is expected to originate from certified low-risk farms.
- **Staple Diversification**: A reduction in reliance on high-risk staples (e.g., rice), with expanded consumption of millet, pulses, and traditional medicinal herbs.

**D. Community Empowerment and Governance Strengthening**

Strengthening participatory governance and enhancing local capacity are critical components for ensuring the sustained impact of food policy interventions targeting CKDu mitigation. This involves the establishment of Functional Food Policy Councils (FPCs) in at least 90% of pilot districts, supported by structured quarterly policy feedback mechanisms to facilitate adaptive governance. Community-led water quality monitoring systems are expected to be active in 80% or more of Grama Niladhari (GN) divisions, with a particular emphasis on mobilizing trained youth brigades to ensure long-term local stewardship. These initiatives are complemented by measurable improvements in community knowledge and civic engagement, evidenced by a doubling of household awareness regarding nephrotoxic substances and food safety labeling practices. Furthermore, a 50% increase in farmer participation in food policy dialogues and governance platforms will reflect greater inclusivity and empowerment within the decision-making processes that influence environmental health and food systems governance.

## 5.7 Monitoring and Evaluation Logic Framework

This section outlines a structured Monitoring & Evaluation (M&E) system that integrates the FAO-TAPE and the City Region Food Systems (CRFS) indicator frameworks to track policy effectiveness, guide iterative improvements, and support evidence-based scaling.

### 5.7.1 Inputs

***Table 5.6: Key Implementation Resources for Policy Execution***

| Resource Type | Description |
|---|---|
| Financial Resources | Secured through government allocations, international development grants, and private-sector co-financing. |
| Human Resources | Engagement of trained personnel including agronomists, environmental scientists, GIS specialists, and community facilitators. |
| Technological Infrastructure | Deployment of GIS software, mobile monitoring applications, and laboratory equipment for environmental and crop residue analysis. |
| Institutional Partnerships | Collaboration with local governance units, universities, public health agencies, and international organizations. |

### 5.7.2 Activities

***Table 5.7: Core Components of the CKDu-Responsive Food Policy Framework***

| Policy Component | Description |
|---|---|
| Environmental Zoning | GIS-enabled spatial analysis to delineate High-Risk Contamination Zones (HRCZs) based on soil and water contaminant levels (e.g., Cd, As, $F^-$). |
| Agroecological Transition | Adoption of sustainable practices such as crop diversification, organic nutrient management (e.g., composting), and soil pH correction through liming. |

| | |
|---|---|
| Food Traceability System | Establishment of a CKDu Food Traceability Network (CFTN) linking geocoded farms with environmental data and food residue profiles. |
| Community Water Interventions | Installation of reverse osmosis (RO) units and solar-powered filtration systems, annual well testing, and participatory "Clean Water Watch" programs. |
| Governance Structures | Creation of District-Level Food Policy Councils (FPCs) to coordinate agrochemical regulation, water safety, and integrated food system planning. |

### 5.7.3 Outputs

***Table 5.8: Key Performance Indicators for Strategic Food Policy Implementation in CKDu-Affected Areas***

| Key Indicator | Description |
|---|---|
| Zoning Maps | High-resolution maps identifying contamination hotspots to target remediation and intervention efforts. |
| Agroecological Uptake | Increased number of farms adopting low-input, biodiversity-enhancing agricultural practices. |
| Traceability Database | Centralized dataset capturing cultivation locations, contaminant levels, and crop output data. |
| Water Safety Infrastructure | Widespread access to clean water through filtration units and real-time transparency in water quality data. |
| Operational FPCs | Functioning Food Policy Councils with regular stakeholder engagement and institutional decision-making authority. |

### 5.7.4 Outcomes

***Table 5.8: Impact Indicators for Evaluating CKDu-Focused Food Policy Outcomes***

| **Impact Area** | **Indicator Description** |
|---|---|
| Contaminant Reduction | Demonstrated ≥50% decline in nephrotoxin levels in crops cultivated within High-Risk Contamination Zones (HRCZs). |
| Agroecological Resilience | Measurable improvements in FAO's TAPE dimensions, with emphasis on soil health, on-farm biodiversity, and reduced pesticide use. |
| Food System Resilience | Development of more diverse and stable agricultural systems that enhance nutritional outcomes and local food sovereignty. |
| Community Engagement | Increased public literacy regarding CKDu-related environmental risks and strengthened community participation in food and environmental governance. |

### 5.7.5 Impact

*Table 5.9: Long-Term Outcome Indicators of Integrated Food Policy for CKDu Mitigation*

| Outcome Domain | Indicator Description |
|---|---|
| Public Health | Long-term reduction in CKDu incidence through decreased exposure to environmental nephrotoxins. |
| Environmental Sustainability | Transition to agroecological production systems that maintain biodiversity and support long-term ecological integrity. |
| Food Security and Sovereignty | Development of a resilient, locally governed food system that ensures access to safe, nutritious, and sustainable food for vulnerable populations. |

### 5.8. Implementation Gantt Chart

- The following Gantt chart outlines the phased implementation of the policy over 5 years:

*Table 5.10: Gannt chart of implementation of food policy*

| Phase | | Action | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|---|---|
| 1 | | **Environmental zoning & baseline mapping** | ✅ | | | | |
| 2 | | **Agroecological pilots in 5 GN divisions** | ✅ | ✅ | | | |
| 3 | | **Traceability system deployment** | | ✅ | | | |
| 4 | | **FPCs and water infrastructure rollout** | | ✅ | ✅ | | |
| 5 | | **Monitoring, scaling, and national policy harmonization** | | | ✅ | ✅ | ✅ |

- **Legend**: ✅ indicates active implementation phase.

## 6. Discussion

This study aimed to develop and evaluate a food policy framework to mitigate Chronic Kidney Disease of unknown etiology (CKDu) in Sri Lanka by integrating agroecological practices, environmental health assessments, and multi-stakeholder perspectives. Through a mixed-methods approach including soil and water quality analyses, stakeholder surveys, and the application of FAO's Tool for Agroecology Performance Evaluation (TAPE) the research identified critical environmental and policy determinants contributing to CKDu prevalence in hotspot regions. Key findings reveal widespread soil and water contamination with nephrotoxic elements such as cadmium Arsenic & Lead, low agroecological performance in monoculture-dominated systems, and significant gaps in policy enforcement and community engagement. By translating scientific evidence into a set of actionable food policy interventions such as environmental zoning, agroecological transitions, and traceability systems this study addresses a major policy blind spot in CKDu mitigation. It fills a crucial gap in the current literature by proposing a systems-based food policy framework that aligns with both national development priorities and international sustainability guidelines, including those of the FAO and WHO.

### 6.1 Methodological Considerations, Remote Coordination, and Replicability

The methodology employed in this study combined field-based environmental assessments, laboratory analyses, community-level surveys, and policy mapping to evaluate potential environmental and socio-political contributors to Chronic Kidney Disease of unknown etiology (CKDu) in selected Sri Lankan regions. The triangulated approach was designed to provide a holistic understanding of CKDu's multifactorial nature, incorporating both empirical data and lived community experiences.

#### Remote Research Coordination: Opportunities and Challenges

One of the defining aspects of this study was that it was coordinated remotely from Sweden while all field activities—including sample collection, community surveys, and stakeholder interviews—were carried out in Sri Lanka. This remote model offered several advantages:

- Efficient Use of Global Expertise: Being based in Sweden allowed the integration of internationally accepted research practices, tools, and standards—such as adherence to ISO/IEC 17025:2017 and USEPA methodologies—into local field operations.
- Digital Collaboration: The use of online platforms enabled real-time monitoring, guidance, and communication with field assistants, laboratory technicians, and community volunteers, maintaining workflow continuity.
- Cost Optimization: Remote coordination significantly reduced travel and accommodation costs without compromising the quality of field engagement.
- Access to Advanced Resources: Being in Sweden also provided access to advanced academic resources and technical consultations that were beneficial in designing and validating survey tools and analytical protocols.

However, several challenges and limitations were also noted:

- Lack of On-Ground Presence: The absence of the principal investigator during field operations limited spontaneous decision-making in unforeseen circumstances (e.g., uncooperative weather, inaccessible locations, participant non-compliance).
- Reliance on Local Capacity: The study was heavily dependent on the accuracy and reliability of trained local personnel. Although they were well-instructed, some degree of variability in sample handling or respondent engagement may have occurred.
- Time Zone Constraints: Coordinating across time zones occasionally led to delays in approvals or adjustments during critical phases like water sampling and stakeholder interviews.
- Limited Sensory Validation: Aspects such as odor, environmental cues, or informal cues from community behavior, which are often valuable in ethnographic and environmental fieldwork, were beyond the direct observation of the principal investigator.

**Reproducibility and Scalability of the Method**

This study's methodology has been documented with transparency and detail to ensure reproducibility:

1. Water and Soil Sampling: Future researchers can replicate the sample collection process by using the same criteria for site selection (e.g., high-prevalence CKDu areas), and adhering to ISO/IEC 17025:2017 protocols for sample testing. It is advisable to engage with accredited laboratories and maintain rigorous chain-of-custody documentation.
2. Community Surveys: The semi-structured questionnaires and focus group formats developed can be reused or adapted for similar socio-cultural settings. Translation accuracy and local facilitator training will be crucial for validity.
3. Stakeholder Interviews: The identification of institutional actors across government, health, and agriculture sectors allows for systematic policy mapping. These interviews should follow a consent-based, semi-structured format to allow open-ended feedback.
4. Water Quality Index (WQI) and Heavy Metal Analysis: The calculation models and threshold values applied in this study are grounded in WHO and SLS standards, enabling direct comparison across different studies and regions.
5. Remote Research Model: The logistical model of remotely conducting research—while challenging—can be duplicated with adequate planning. It is essential to establish a clear communication hierarchy, use digital tools for coordination (e.g., shared dashboards, mobile data collection apps), and invest in training for local teams.

**Ethical and Logistical Reflections**

Ethical clearance and local stakeholder engagement were prioritized to build trust and minimize disruption to communities. Conducting this study remotely also demonstrated that meaningful international collaborations can support research in developing countries without physical presence, provided that cultural sensitivity, ethical standards, and technical rigor are upheld.

In future replications or expansions of this research model, it is recommended to:

- Implement a pilot phase to test remote protocols.
- Use GPS-tagged and time-stamped field data to increase traceability.
- Integrate local academic partners for on-ground validation and sustainability.

## 6.2 Environmental Contamination: Soil and Water Quality as Drivers of CKDu

The results of this study provide robust evidence that environmental contamination specifically in soil and drinking water plays a central role in the etiology and spatial persistence of CKDu in Sri Lanka's North Central and Uva provinces. Heavy metal analyses revealed elevated concentrations of cadmium (Cd), arsenic (As), and lead (Pb) in both water and soil samples across surveyed CKDu hotspots. Notably, water samples from Hingurakgoda and Dimbulagala contained alarmingly high levels of arsenic (21.8 µg/L and 19.8 µg/L, respectively), significantly exceeding the WHO guideline of 10 µg/L for drinking water (WHO, 2017). Cadmium levels also breached the 0.003 mg/L threshold in nearly all sampled locations, with the highest concentration observed in Hingurakgoda (1.28 µg/L), which correlates with the highest Water Quality Index (WQI) score (166.14), suggesting severely impaired water quality.

Similarly, soil analysis demonstrated widespread contamination. Sites such as Padaviya, Elahera, and Medirigiriya exhibited Pollution Load Index (PLI) values above 2.0, indicating high cumulative pollution burden. Elahera showed the highest average concentrations of arsenic (22.76 mg/kg) and lead (81.6 mg/kg), alongside a high Cd enrichment factor (Cf(Cd) = 2.28). These findings are consistent with prior studies that have linked CKDu prevalence to cumulative nephrotoxic exposure from agricultural soils and contaminated groundwater (Jayasumana et al., 2015; Herath et al., 2018). Chronic ingestion of trace nephrotoxins through drinking water and food cultivated in polluted soils likely accelerates renal damage, especially in populations already burdened by heat stress and dehydration due to manual labor in paddy farming (Kjellstrom et al., 2016).

While the specific causative mechanisms of CKDu remain under investigation, bioaccumulation of heavy metals through dietary exposure is increasingly supported as a plausible pathway. Jayasumana et al. (2014) found glyphosate–metal complexes in hard water regions of Sri Lanka, which may act as carriers for cadmium and arsenic, further supporting the hypothesis of environmental nephrotoxicity. The concentrations observed in this study not only affirm these earlier findings but also suggest spatially persistent contamination patterns aligned with CKDu prevalence zones.

The deterioration of water quality parameters such as elevated BOD, low dissolved oxygen, and high turbidity across most areas indicates organic and chemical pollution likely exacerbated by agricultural runoff. These values further compromise the potability of drinking water, intensifying chronic kidney stress. For example, Hingurakgoda recorded the highest BOD (4.58 mg/L), lowest DO (3.78 mg/L), and the highest turbidity (7.98 NTU), suggesting advanced water quality degradation—conditions unfavorable for long-term human consumption and consistent with renal toxicological risk (Bandara et al., 2008).

In global comparison, the findings resonate with environmental patterns identified in Mesoamerican Nephropathy (MeN), where heavy metal exposure and agrochemical runoff are associated with high CKD prevalence in sugarcane farming regions (Orantes-Navarro et al., 2017; Gonzalez-Quiroz et al., 2018). However, unlike in Central America where dehydration and heat stress are often emphasized, the Sri Lankan context also involves sustained oral ingestion of environmental nephrotoxins, further underscoring the need for integrative food and environmental policy interventions.

This evidence supports the thesis that any effective CKDu mitigation strategy must prioritize food system interventions—such as regulation of agrochemical use, remediation of contaminated agricultural soils, and the provision of safe water sources—within a coherent policy framework. These findings provide scientific justification for the soil zoning, agroecological transition, and water traceability measures proposed in the strategic food policy formulated in this study.

### 6.3 Food System & Agrochemical Practices

The current food system in CKDu-endemic regions of Sri Lanka reflects a troubling pattern of agrochemical overuse, minimal product traceability, and limited awareness among both input suppliers and farmers. Survey findings from agricultural input suppliers indicate that the majority operate without sufficient training on the health or environmental risks of agrochemicals. Although 82% acknowledged distributing glyphosate and other high-risk substances, less than 20% reported any awareness of these products' potential nephrotoxicity (Appendix A, Fig. 1). Furthermore, over half of the suppliers did not require or verify farmer training prior to the sale of restricted-use agrochemicals, raising serious concerns about compliance with national pesticide regulations (Registrar of Pesticides, 2021).

Farmers, in parallel, rely heavily on chemical inputs to maintain productivity under increasingly unpredictable climatic conditions. However, this reliance is often coupled with unsafe handling, poor application practices, and limited protective measures. Field interviews revealed common practices such as mixing multiple agrochemicals without guidance, reusing contaminated water for irrigation, and failing to follow withholding periods before harvest. These practices increase the likelihood of chronic toxic exposure not only for the farmers but also for downstream consumers who depend on local produce (Jayasumana et al., 2015a; Herath et al., 2018).

The food system's lack of transparency and traceability further compounds the problem. Both suppliers and local health officials expressed concern over the absence of a system to track pesticide use along the food chain—from input sale to consumer markets. Without traceability, contaminated food cannot be reliably identified or removed from circulation, limiting the ability of public health authorities to respond to toxic exposure events or to conduct effective surveillance (FAO, 2020). These issues reflect a structurally flawed supply chain that facilitates the silent circulation of nephrotoxic residues in rural diets and ecosystems, ultimately contributing to the persistence of CKDu in affected communities.

### 6.4 Policy and Governance Gaps

Policy and governance-related deficits form a critical barrier to effective CKDu mitigation. Survey responses from policymakers and public health officials highlight multiple systemic weaknesses, particularly in regulatory enforcement, inter-agency coordination, and food monitoring. While Sri Lanka has introduced various bans and restrictions on specific agrochemicals, enforcement remains inconsistent. Over 70% of policymakers surveyed reported limited field monitoring capacity and inadequate staffing to conduct inspections or follow up on reported violations (Appendix B, Fig. 2).

This governance gap is exacerbated by fragmented institutional mandates. Ministries responsible for health, agriculture, and environment often operate in silos, with little intersectoral dialogue or collaborative action. For example, while the Ministry of Health is tasked with public health surveillance, it lacks direct access to real-time agricultural input data, impeding efforts to correlate food-borne exposures with disease outbreaks. Similarly, agricultural extension services are not systematically trained to communicate CKDu risks, particularly those arising from agrochemical residues or dietary exposure pathways (WHO, 2017; Wanigasuriya, Peiris-John & Wickremasinghe, 2011, p.32).

A particularly alarming concern is the absence of a national food traceability system. Without such a mechanism, food safety enforcement is reactionary rather than preventive, relying on limited spot-checks rather than a continuous monitoring framework. Policymakers acknowledged that this lack of traceability severely limits the capacity to regulate nephrotoxin exposure in food products, especially in rural and informal markets. Moreover, efforts to introduce participatory governance mechanisms—such as multi-stakeholder food safety councils or agroecological zoning committees—remain underdeveloped, despite being recommended in national strategies (Ministry of Health, 2021; FAO & WHO, 2019).

These findings suggest that without institutional reforms and integrated policy responses, technical interventions alone will be insufficient to disrupt the environmental and dietary determinants of CKDu. Strengthening inter-agency governance, enhancing local enforcement capacity, and establishing digital traceability frameworks must be prioritized within national food policy agendas to enable systemic change.

### 6.5 NABC Framework: Value Proposition of a Food Policy for CKDu Mitigation

The development of a food policy framework to address Chronic Kidney Disease of unknown etiology (CKDu) in Sri Lanka aligns well with the NABC model—an innovation-centric structure that emphasizes *Need*, *Approach*, *Benefit*, and *Competition* (Carlson & Wilmot, 2006).
**Need:** The research establishes a clear, multidimensional need: rural communities face sustained toxic exposures from agrochemicals, unmonitored food systems, and unsafe water—factors contributing to the persistence of CKDu. Both health workers and agricultural stakeholders affirmed the urgency of an integrated, preventive response (Section A–C).
**Approach:** The thesis proposes a comprehensive food policy that integrates strategic agroecological zoning, traceability systems, and participatory food governance. This

multisectoral approach directly addresses systemic gaps identified in the survey data and promotes cross-ministerial cooperation (Ministry of Health, 2021; FAO & WHO, 2019).
**Benefit:** The proposed policy enhances public health outcomes by reducing dietary and environmental nephrotoxins while promoting sustainable agricultural practices. It also offers long-term benefits such as reduced health system burden, improved soil and water quality, and greater food system transparency.
**Competition:** Existing responses to CKDu are primarily biomedical or focused on isolated interventions (e.g., well water filters or agrochemical bans). These approaches lack systemic integration and have failed to reverse CKDu trends. In contrast, the proposed food policy offers a proactive, systems-level alternative rooted in food system reform and preventive health.

### 6.6 Diffusion of Innovations: Barriers and Pathways to Agroecological Transition

Rogers' (2003) Diffusion of Innovations theory offers a useful lens to interpret both the challenges and opportunities associated with scaling agroecological transitions in CKDu-endemic areas. Agroecology represents an innovation in both practice and paradigm, requiring shifts in beliefs, behaviors, and institutional incentives.
Key barriers identified in the study include:

- **Low awareness and risk perception** among farmers and suppliers regarding the health risks of agrochemical use.
- **Institutional inertia** and siloed governance structures that inhibit horizontal learning and cross-sector policy uptake.
- **Economic and market constraints**, such as the lack of price incentives or subsidies for low-input, ecologically safe farming.

However, the survey also revealed several enablers of diffusion:

- **Local champions and extension agents** willing to promote ecological farming if better resourced.
- **Community openness** to dietary and farming changes when linked to tangible health benefits.

For agroecological innovations to be adopted widely, interventions must align with Rogers' five attributes of innovation: relative advantage, compatibility with existing values, simplicity, trialability, and observability. Pilot programs using agroecological demonstration plots and participatory training could enhance trialability and observability, increasing adoption rates among rural populations (Rogers, 2003).

### 6.7 FAO's TAPE Framework: Global Benchmarking of Agroecological Policy

The FAO's Tool for Agroecology Performance Evaluation (TAPE) provides a structured framework to evaluate how well national food systems integrate agroecological principles (FAO, 2019). This thesis aligns with several key elements of TAPE's performance domains:

- **Enabling Environment:** The policy proposal strengthens governance through participatory councils, enhances farmer agency, and increases public awareness—core enabling conditions in TAPE.
- **Agroecological Practices:** Field-level transitions proposed in this study—such as organic input subsidies, soil testing services, and biodiversity-friendly cropping—are consistent with the 10 Elements of Agroecology (FAO, 2018).

- **Socioeconomic Resilience:** By targeting the structural determinants of rural health and environmental degradation, the policy supports both ecological and socioeconomic resilience.

The policy also responds to TAPE's call for cross-cutting indicators such as human health impacts, gender equity, and climate adaptation. While not all dimensions were addressed in equal depth, the findings set the stage for future integration of these indicators into national planning frameworks.

**Implications for Food Policy and CKDu Mitigation**

The findings of this thesis strongly support the urgent need to reorient Sri Lanka's food policy through an integrative, cross-sectoral framework that addresses the underlying environmental determinants of Chronic Kidney Disease of Unknown Etiology (CKDu). The observed contamination of soil and water with cadmium, arsenic, fluoride, and nitrates—particularly in intensively farmed regions—underscores the systemic toxicity embedded in current agricultural production regimes. These contaminants are likely linked to long-term agrochemical use, poor soil buffering capacity, and hydrological transport pathways, which together contribute to dietary and hydric exposure risks (Jayasumana et al., 2014; WHO, 2019).
To mitigate these exposures, **strategic zoning** should be implemented to demarcate high-risk agricultural areas and transition them into low-input, monitored agroecological zones. This zoning must be supported by spatial soil and water testing, health surveillance data, and climate vulnerability mapping (Perera et al., 2020). The incorporation of **community governance councils**—comprising farmers, health workers, and local authorities—can ensure democratic oversight and responsiveness to local ecological knowledge. These councils could coordinate agrochemical use, manage shared water resources, and monitor implementation of health warnings, thereby operationalising the FAO's call for territorial governance of food systems (FAO, 2021).
**Food traceability systems** must also be institutionalised. Survey results revealed a near-total absence of traceability mechanisms among agrochemical input suppliers and farmers. Without traceability, consumers remain exposed to contaminated produce, and policy enforcement is rendered ineffective. Mandating digital registries of input use, supported by local cooperatives or extension services, could dramatically improve transparency and accountability in the food chain (Liu et al., 2021).
Agroecology emerges as a foundational pathway to build system resilience. Surveyed farmers and community members showed willingness to adopt ecological practices if institutional and technical support is provided. Agroecology can buffer environmental stressors, regenerate soil microbiomes, and enhance water retention, directly reducing CKDu-linked exposure risks (Altieri & Nicholls, 2017). The FAO's Tool for Agroecology Performance Evaluation (TAPE) used in this study affirms that agroecological practices scored higher in biodiversity, input reduction, and social inclusion, making them highly suitable for sustainable rural transformation.

### 6.8 Limitations of the Study

This research is subject to several limitations. Geographically, the study focused primarily on CKDu-endemic regions of the **North Central province**, potentially limiting the generalisability of findings to other agroecological zones in Sri Lanka. Moreover, the **survey sample sizes**, while stratified across communities, policymakers, and input suppliers, were constrained by resource availability and may reflect **selection biases** related to literacy, health awareness, or willingness to participate.

**Temporal limitations** must also be acknowledged, as soil, water, and survey data were collected during a single agricultural season (February to March). Seasonal fluctuations in rainfall, irrigation practices, and chemical use could influence contaminant concentrations and exposure pathways. Additionally, while laboratory tests adhered to international protocols, **measurement uncertainties** inherent in field sampling and analytical techniques may introduce variability, particularly in trace element detection at low concentrations.

Despite these limitations, the triangulation of soil and water data with stakeholder perceptions and institutional insights offers a robust basis for policy inference. This multi-scalar integration reflects the interdependence of environmental, agricultural, and health systems in CKDu-affected landscapes.

### 6.9 Recommendations for Future Research

To strengthen the policy and practice implications of this study, several focused research directions are proposed:

- Conduct longitudinal field studies in CKDu hotspots to trace environmental and dietary exposures using biomarkers of nephrotoxicity.
- Support community-led agroecological field trials in endemic zones to assess impacts on soil health, yield, and human wellbeing.
- Pilot traceability and zoning regulations, with rigorous monitoring and evaluation to gauge feasibility, enforcement, and outcomes.
- Expand the use of the FAO TAPE tool across agro-ecological zones to inform national agroecological transition strategies.

These recommendations emerge directly from this study's empirical findings, highlighting the need for adaptive, participatory, and evidence-informed interventions. CKDu is not solely a clinical issue but a consequence of systemic failures in Sri Lanka's food, environment, and public health governance. This study demonstrates that a strategically designed, community-informed food policy emphasizing zoning, traceability, and ecological farming can offer a path toward resilience

## 7. Conclusion

This thesis has revealed a multi-layered understanding of Chronic Kidney Disease of unknown etiology (CKDu) in Sri Lanka, placing environmental degradation, agricultural practices, and food systems at the center of its pathogenesis.

### 7.1 Core Insights and Discoveries

Through a mixed-methods approach encompassing environmental sampling, community and stakeholder surveys, GIS mapping, and agroecological assessment via FAO's Tool for Agroecology Performance Evaluation (TAPE), the study confirmed that nephrotoxic agrochemicals, poor water quality, and soil contamination are interlinked with the spatial prevalence of CKDu.

Survey data from farmers, community members, healthcare workers, and input suppliers highlighted both widespread awareness and alarming gaps in safe chemical use, protective practices, and understanding of long-term health consequences. Soil and water analysis revealed elevated levels of heavy metals and agrochemical residues in high-risk zones, directly correlating with CKDu hotspots (Jayasumana et al., 2015; Dharma-wardana, 2018). Furthermore, healthcare providers emphasized delayed diagnosis due to the absence of early biomarkers and limited rural infrastructure (Wimalawansa, 2016c).

The TAPE assessment demonstrated the agroecological unsustainability of prevailing farming systems in CKDu-endemic regions, revealing low scores in environmental resilience, health safety, and governance participation validating the urgent need for system-wide transition (FAO, 2021).

### 7.2 Broader Implications and Real-World Impact

The implications of this research extend beyond environmental health into food systems governance and public policy. By framing CKDu not merely as a biomedical issue but as a food policy failure, the study challenges siloed approaches and calls for integrated solutions. It strengthens the growing body of global evidence suggesting that chronic exposure to agrochemicals often unregulated and misused is a fundamental driver of kidney disease in rural agrarian economies (Weaver et al., 2019; Orantes-Navarro et al., 2017).

Through the application of frameworks such as Rogers' Diffusion of Innovation Theory (Rogers, 2003) and the NABC model (Stanford Research Institute, 2002), this thesis formulated five actionable policy pillars: (1) Spatial Risk-Based Food Production Zoning, (2) CKDu-Safe Farming through Agroecological Intensification, (3) Food Chain Traceability and Safety Governance, (4) Community-Scale Water Safety Infrastructure, and (5) Local Governance through Food Policy Councils (FPCs). These interventions are informed by empirical findings and grounded in participatory, evidence-based planning.

This thesis shows that improving food policy is not only a tool for CKDu mitigation but also a vehicle for achieving rural health equity, environmental protection, and climate-resilient food systems. The proposed Monitoring & Evaluation Framework, rooted in science-based indicators (e.g. contamination indices, agroecological performance, CKDu incidence rates), provides a roadmap for long-term policy accountability and impact assessment.

### 7.3 Study Constraints and Opportunities for Enhancement

Despite its comprehensive approach, this study faced several limitations. The geographic scope was constrained to selected high-prevalence districts, potentially limiting generalizability to other national or international contexts. Furthermore, while water and soil quality were rigorously tested, other environmental stressors such as air pollution, heat stress, and occupational exposures were outside the study's scope but may play contributory roles (ILO, 2020).

Agrochemical exposure was inferred through environmental sampling and stakeholder reporting, without the benefit of individual biomonitoring. Future studies could employ longitudinal tracking and direct exposure analysis to deepen causal insights.
While the TAPE tool offered a robust sustainability snapshot, limited farmer training and understanding of ecological indicators may have influenced scoring consistency. Future iterations could incorporate extended training and seasonal assessments for validation (FAO, 2021).

### 7.4 Future Research Directions

This thesis opens important avenues for interdisciplinary research into CKDu and its structural determinants. **Longitudinal epidemiological studies** are critical to establish robust causal pathways between chronic exposure to agrochemical contaminants and kidney dysfunction (Gifford et al., 2017). Development of **early diagnostic tools**, such as non-invasive biomarkers, remains an urgent gap (Nanayakkara et al., 2014).
Further inquiry should explore the **economic and behavioral dimensions** of agroecological transitions, particularly the scalability, affordability, and adoption dynamics of sustainable practices. Institutional research into **governance culture, regulatory enforcement, and farmer cooperation** could inform effective policy implementation.
Comparative research across global CKDu hotspots — including Central America, India, and Southeast Asia — may enrich understanding of **shared environmental nephropathies** and foster international cooperation in agrochemical regulation, food policy harmonization, and health system readiness.

### 7.5 Concluding Thoughts: Bridging Knowledge and Action

This thesis provides a scientifically grounded and policy-relevant contribution to the understanding and mitigation of CKDu in Sri Lanka. By positioning food policy at the intersection of environment, health, and agriculture, it demonstrates the power of integrative governance to address complex chronic diseases. The proposed strategic interventions, rooted in participatory evidence and agroecological principles, represent a tangible path forward—not just for CKDu-affected regions, but for all contexts where agricultural modernity has outpaced environmental and health safeguards.
Ultimately, the future of CKDu mitigation lies in shifting from reactive health care to proactive environmental stewardship. This research bridges the gap between science and policy, offering a transformative agenda for sustainable food systems, resilient communities, and health justice in the face of environmental disease.

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**Appendix**

**Appendix A: Survey and Interview Questionnaire**

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**1. Survey for Farmers & Agricultural Workers**

**Section A: Demographics**

1. Age: _____
2. Gender: ☐ Male ☐ Female ☐ Other
3. Location (District/Village): __________
4. Education Level: ☐ No formal education ☐ Primary ☐ Secondary ☐ Higher education
5. Number of years in farming: _____
6. Household size: _____
7. Monthly household income: ☐ Low ☐ Moderate ☐ High

**Section B: Agricultural Practices & Fertilizer Usage**

8. What crops do you cultivate?

(Check all that apply) ☐ Rice ☐ Vegetables ☐ Fruits ☐ Other (Specify: __________)

9. How frequently do you use fertilizers/pesticides?

☐ Daily ☐ Weekly ☐ Monthly ☐ Rarely ☐ Never

10. What type of fertilizers/pesticides do you use?

☐ Organic ☐ Chemical ☐ Both

11. Are you aware of the health risks associated with fertilizer and pesticide use?

☐ Yes ☐ No

12. Have you received training on the safe use of agrochemicals?

☐ Yes ☐ No

13. Do you use protective equipment while handling agrochemicals?

☐ Yes ☐ No

**Section C: Health & Exposure**

14. Have you or anyone in your family been diagnosed with kidney disease?

☐ Yes ☐ No

15. Do you experience any of the following symptoms?

(Check all that apply) ☐ Fatigue ☐ Back pain ☐ Frequent urination ☐ Swelling in legs ☐ None

16. Have you sought medical help for these symptoms?

☐ Yes ☐ No 17. Do you have a family history of kidney disease? ☐ Yes ☐ No

**Section D: Drinking Water & Working Conditions**

18. What is your primary drinking water source?

☐ Well ☐ Tap ☐ River ☐ Bottled

19. How often do you treat or filter your drinking water?

☐ Always ☐ Sometimes ☐ Never

20. Do you work in high temperatures for long hours?

☐ Yes ☐ No

21. Do you take adequate water breaks during work?

☐ Yes ☐ No

22. What measures do you take to protect yourself from extreme weather conditions?

___________

**Section E: Dietary Habits & Eating Patterns**

23. What foods do you consume daily?

(Check all that apply) ☐ Rice ☐ Vegetables ☐ Fruits ☐ Processed food ☐ Meat

24. Do you wash your vegetables before consumption?

☐ Always ☐ Sometimes ☐ Never

25. How many meals do you eat per day?

☐ 1 ☐ 2 ☐ 3 ☐ More than 3

26. Do you consume fast food or packaged foods regularly?

☐ Yes ☐ No

27. Do you include high-protein foods (e.g., fish, eggs, meat, legumes) in your diet?

☐ Yes ☐ No

**2. Survey for Agricultural Product Suppliers**

**Section A: Business & Product Information**

1. What types of fertilizers/pesticides do you sell?

   ☐ Organic ☐ Chemical ☐ Both

2. How long have you been in the agricultural supply business? _____ years
3. Who are your primary customers? ☐ Small-scale farmers

   ☐ Large-scale farmers ☐ Agro-industrial businesses

4. What are the most commonly sold agrochemicals in your shop? __________

**Section B: Awareness & Regulations**

5. Are customers aware of agrochemical risks?

   ☐ Yes ☐ No

6. Do you provide safety guidance when selling pesticides?

   ☐ Yes ☐ No

7. Have you received formal training on agrochemical safety?

   ☐ Yes ☐ No

8. What regulations do you follow for chemical sales?

   __________

9. Do you think current policies on agrochemical sales are effective?

   ☐ Yes ☐ No

**Section C: Market & Challenges**

10. What are the biggest challenges in selling safer agricultural alternatives?

    ☐ Cost ☐ Low demand ☐ Lack of awareness ☐ Limited supply

11. Have you observed any changes in customer preferences for fertilizers/pesticides?

    ☐ Yes ☐ No

12. Do you think farmers are shifting towards organic farming?

    ☐ Yes ☐ No

13. Are there government incentives to promote organic/safe farming practices?

    ☐ Yes ☐ No

14. What improvements would you suggest for agrochemical regulations?

**Section D: Business Ethics & Environmental Responsibility**

15. Do you educate farmers on responsible pesticide use?

    ☐ Yes ☐ No

16. Are there restrictions on certain chemicals due to health/environmental concerns?

    ☐ Yes ☐ No

17. Have you faced any penalties or warnings for non-compliance with regulations? ☐ Yes ☐ No

18. Do you support government initiatives promoting sustainable farming?

    ☐ Yes ☐ No

19. Do you believe agrochemical suppliers have a role in reducing CKDu cases?

    ☐ Yes ☐ No

20. How can the government better support agrochemical suppliers in promoting safe farming?

    ___________

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**3. Survey for Healthcare Providers**

**Section A: Professional Background**

1. Your role:

   ☐ Doctor ☐ Nurse ☐ Public health officer ☐ Other (Specify: ________)

2. Years of experience in treating kidney diseases: ______

3. Have you received special training on CKDu?

   ☐ Yes ☐ No

**Section B: CKDu Cases & Diagnosis**

4. How many CKDu cases have you treated in the last year?
   ☐ 1-10 ☐ 11-50 ☐ 51-100 ☐ More than 100
5. What symptoms do most CKDu patients report?
   (Check all that apply)
   ☐ Fatigue ☐ Back pain ☐ Reduced urine output ☐ Swelling in legs ☐ Other (Specify: ________)
6. What are the challenges in diagnosing CKDu?

(Check all that apply)

☐ Late detection ☐ Limited resources ☐ Lack of awareness ☐ Other (Specify: __________)

7. Do you see common patterns in affected individuals?
   (Check all that apply)
   ☐ Farmers ☐ Men ☐ Women ☐ Individuals with prolonged pesticide exposure

**Section C: Treatment & Prevention**

8. What are the main treatment options available for CKDu patients?
   1. (Check all that apply)
      ☐ Dialysis ☐ Medication ☐ Lifestyle changes ☐ No treatment available

**9.** Based on your experience, what are the recovery and death rates of CKDu patients?

   **1.** Recovery rate: **______%**

   **2.** Death rate: **______%**

10. What preventive measures should be prioritized? (Check all that apply)
    1. ☐ Reducing agrochemical exposure ☐ Improving water quality ☐ Public education ☐ Dietary interventions
11. Are there sufficient healthcare facilities to manage CKDu cases?
    ☐ Yes ☐ No
12. How does weather and dehydration contribute to CKDu cases in your observation?

    ________________________________________________________________

    ________________________________________________________________

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**3. Survey for Community Members**

**Section A: Policy Awareness & Implementation**
(Note: Some policy-related data may be obtained from secondary sources for accuracy.)

1. Based on your experience, how effectively are agrochemical regulations enforced in Sri Lanka?

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2. In your opinion, are the existing government measures sufficient to reduce CKDu risks? If not, what additional steps should be taken?

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3. What are the main challenges in enforcing food safety regulations from a policy perspective?

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4. How does climate change impact agricultural practices and CKDu risk in Sri Lanka?

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5. Do you believe existing food safety policies are effective? Why or why not?

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6. What are the barriers to implementing stricter fertilizer and pesticide regulations?

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**Section 2: Future Policy Recommendations**

7. What policy actions should the government take to mitigate CKDu?
    - Ban harmful pesticides?__________________
    - Promote organic farming? __________________
    - Improve drinking water standards? __________________
    - Strengthen healthcare facilities? __________________

8. How effective do you think current policies are in addressing CKDu? What improvements are needed?

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9. What resources are needed to enhance CKDu prevention efforts? (e.g., more funding, stronger regulations, public awareness campaigns, research & development investments, etc.)

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10. What types of collaboration are needed between the government, farmers, and healthcare professionals to effectively combat CKDu?

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**5. Survey for Community Members**

**Section A: Demographics & Household Information**

1. Age: _____
2. Gender: ☐ Male ☐ Female ☐ Other
3. Location (District/Village): __________
4. Education Level: ☐ No formal education ☐ Primary ☐ Secondary ☐ Higher education
5. Occupation:
   ☐ Farmer ☐ Laborer ☐ Government Employee ☐ Other
6. Monthly household income:

   ☐ Low (Below LKR 35,000) ☐ Moderate (Between LKR 35,000 and LKR 75,000)

   ☐ High (Above LKR 75,000)

**Section B: Health & CKDu Awareness**

7. Do you or any family members suffer from CKDu?
   ☐ Yes ☐ No
8. Have you received any medical advice regarding CKDu prevention?
   ☐ Yes ☐ No
9. What symptoms have you or affected family members experienced?
   ☐ Fatigue ☐ Back pain ☐ Frequent urination ☐ Swelling ☐ Other
10. How often do you seek medical check-ups for kidney health?
    ☐ Regularly ☐ Occasionally ☐ Rarely ☐ Never

**Section C: Drinking Water & Sanitation**

11. What is your primary drinking water source?
    ☐ Well ☐ Tap ☐ River ☐ Bottled
12. Do you treat or filter your drinking water?
    ☐ Always ☐ Sometimes ☐ Never
13. Have you noticed any changes in water quality in recent years?
    ☐ Yes ☐ No

    **If yes, please describe the changes you have observed:**

14. Do you use any alternative water sources during droughts?
    ☐ Yes ☐ No

**Section D: Diet & Nutrition**

15. What foods do you consume daily?
    ☐ Rice ☐ Vegetables ☐ Fruits ☐ Processed food ☐ Meat
16. Do you wash your vegetables before consumption?
    ☐ Always ☐ Sometimes ☐ Never
17. How many meals do you eat per day?
    ☐ 1 ☐ 2 ☐ 3 ☐ More than 3
18. Do you consume fast food or packaged foods regularly?
    ☐ Yes ☐ No
19. Have you received any education or information on kidney-friendly diets?
    ☐ Yes ☐ No

**Section E: Environmental & Lifestyle Factors**

20. Are you exposed to pesticides/agrochemicals?
    ☐ Yes ☐ No
21. Do you experience heat stress due to working conditions?
    ☐ Yes ☐ No

22. How frequently do you drink water during farming activities?
□ Every 30 minutes □ Every 1 hour □ Occasionally □ Rarely

23. What preventive measures do you take regarding food and water safety? __________

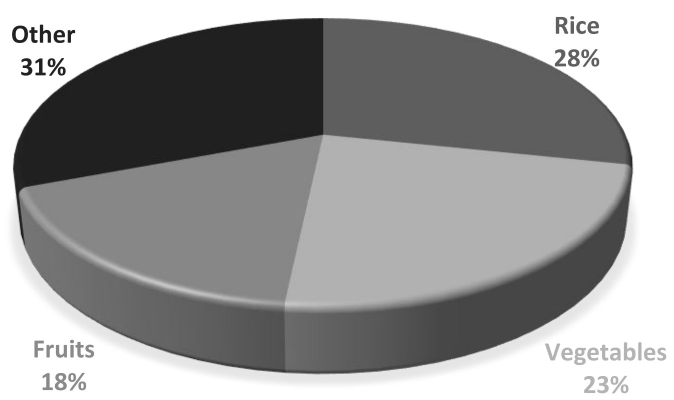
**Appendix B: Findings of Survey and Interview Questionnaire**

**1. Farmers survey**

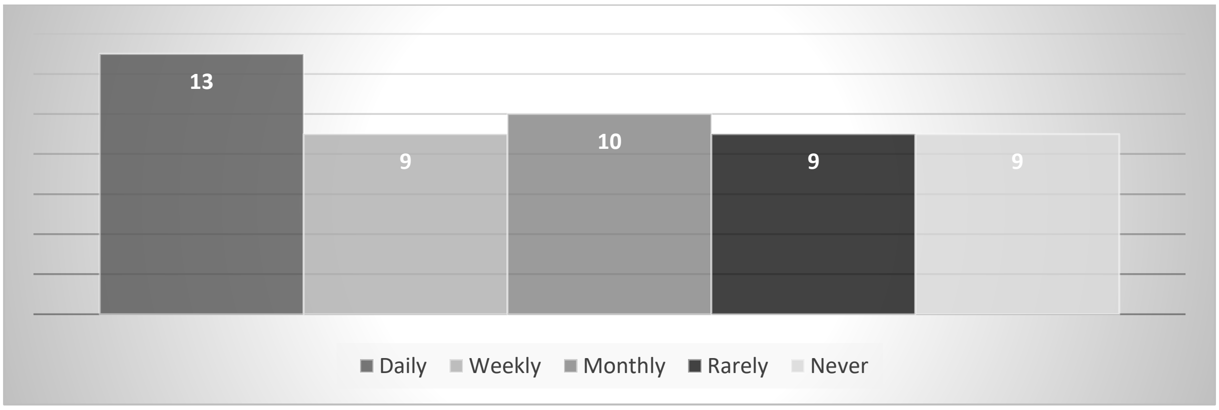
**A. General details**

| Category | Details |
|---|---|
| Total Respondents | 50 |
| Gender Distribution | Male: 23, Female: 27 |
| Age | Range: 26–65 years<br>Average: ~44 years |
| Locations Represented | 5 numbers of farmers from each hotspot |
| Education Levels | No formal education: 9<br>Primary: 13<br>Secondary: 13<br>Higher education: 15 |
| Years in Farming | Range: 1–40 years<br>Average: ~23 years |
| Household Size | Range: 2–8 members<br>Most common: 4–6 members |
| Monthly Income Levels | High: 20Moderate: 15Low: 15 |

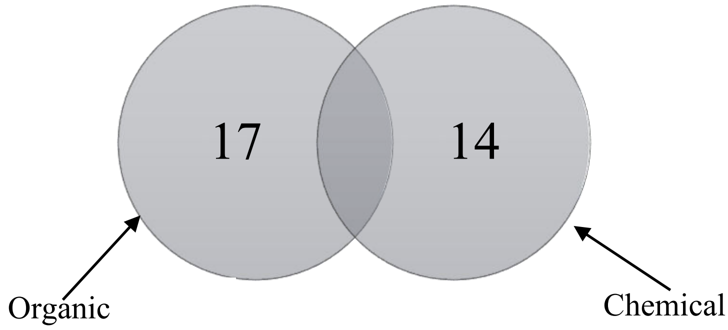
**B. Crops cultivated**



### C. Fertilizer using frequency

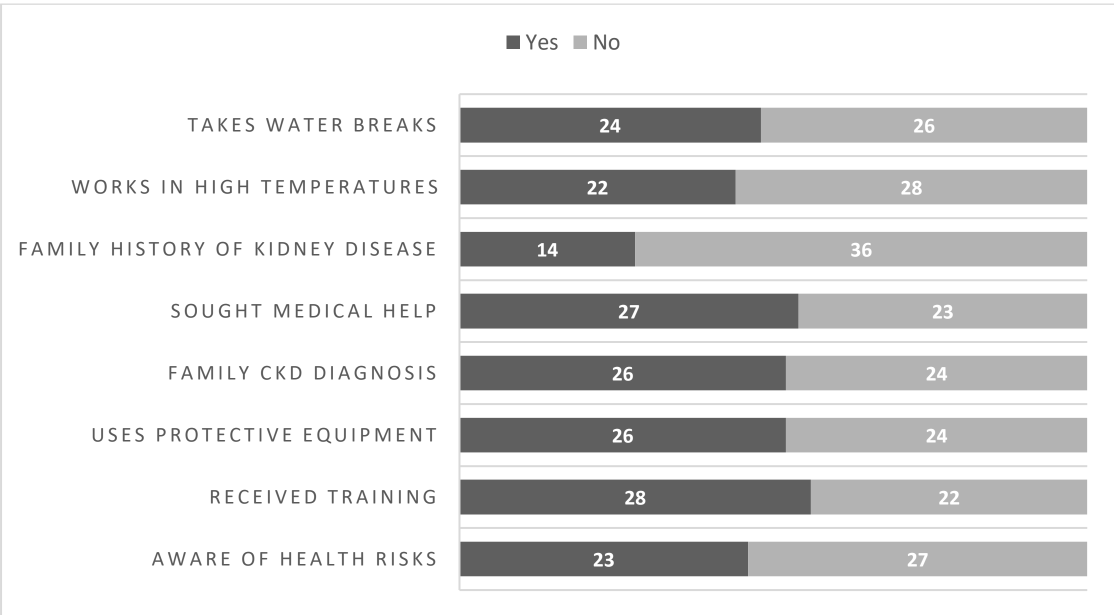



### D. Fertilizer Type vs Number of Farmers



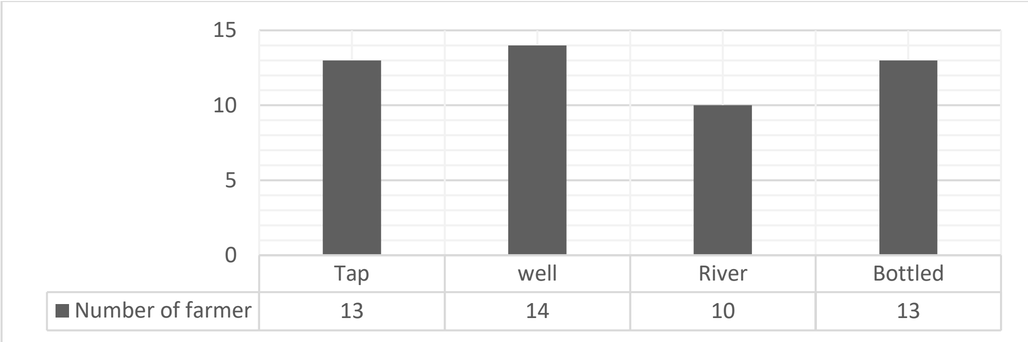

**N=50**

### E. Aggregated Overview of Occupational Health Awareness, Preventive Practices, and Renal Risk Indicators Among Farmers.

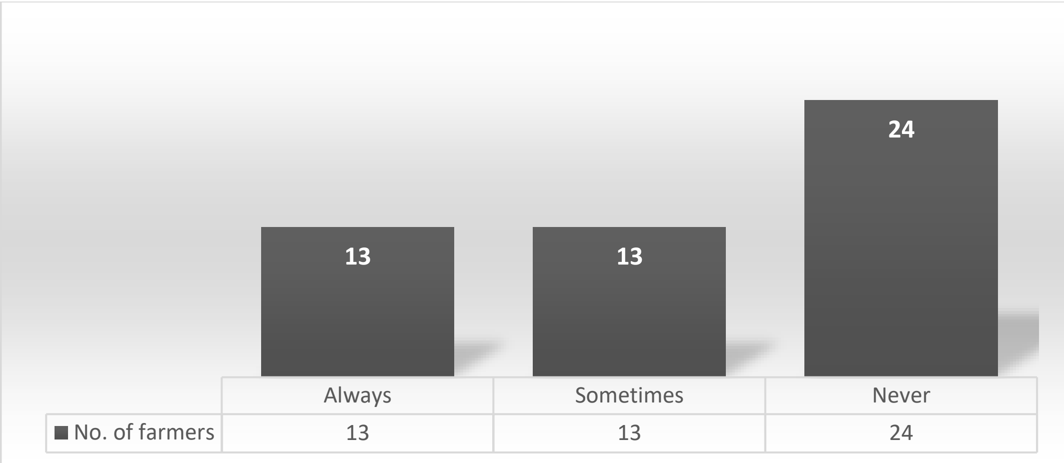


**F. Distribution of Drinking Water Sources and Treatment Practices Among Agricultural Workers.**

**Water source**




**Frequency of Water Treatment Among Farmers**

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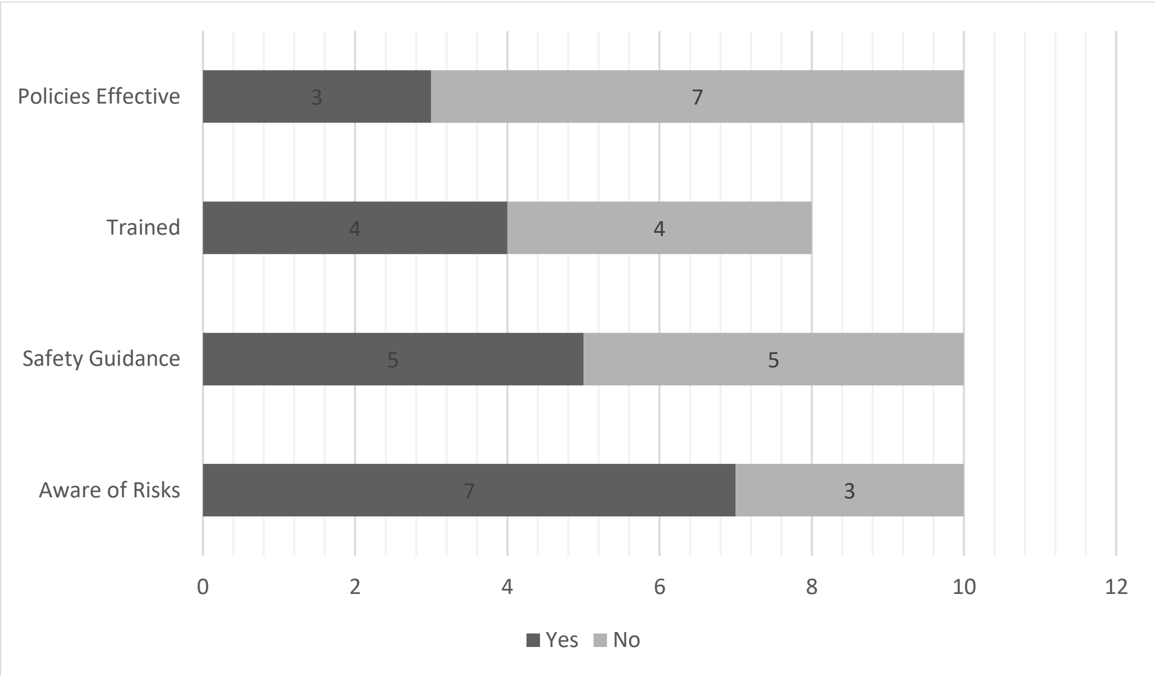
## 2. Survey for Agricultural Product Suppliers

### A. General details.

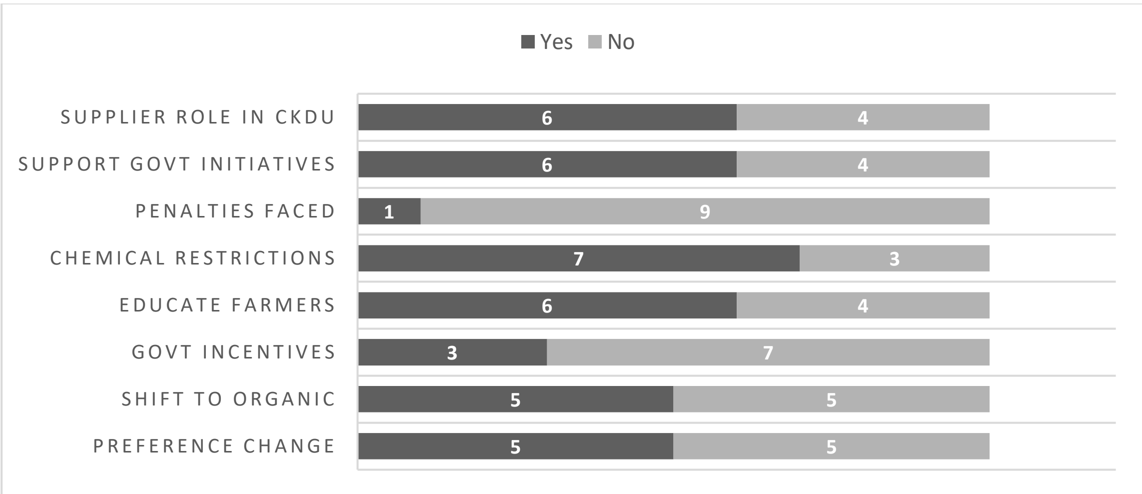
| Location | Fertilizer Type | Years in Business | Primary Customers | Top Chemicals |
|---|---|---|---|---|
| Medawachchiya | Chemical | 12 | Small-scale farmers | Urea, Glyphosate |
| Dimbulagala | Both | 8 | Large-scale farmers | Compost, MOP |
| Elahara | Organic | 5 | Small-scale farmers | Compost, Biofertilizers |
| Rambewa | Chemical | 18 | Agro-industrial businesses | Glyphosate, Urea |
| Hingurakgoda | Both | 10 | Small-scale farmers | Compost, Urea |
| Horowpathana | Chemical | 20 | Large-scale farmers | MOP, Glyphosate |
| Kahatagasdigiliya | Both | 9 | Small-scale farmers | Organic mix, Compost |

| | | | | |
|---|---|---|---|---|
| **Padaviya** | **Chemical** | **7** | **Small-scale farmers** | **Glyphosate, Urea** |
| **Medirigiriya** | **Organic** | **6** | **Small-scale farmers** | **Compost, Neem-based** |
| **Elahara (2)** | **Chemical** | **15** | **Agro-industrial businesses** | **MOP, Urea** |

## B. Impact of knowledge




## C. Stakeholder Response Summary on Agrochemical Practices and Policy Interventions



### 3. Survey of health care providers

### A. Number of Professionals and Experience Range

| Profession | Number of Professionals | Experience Range (Years) |
|---|---|---|
| Doctor | 7 | 12–22 |
| Nurse | 5 | 4–9 |
| Public health officer | 3 | 8–11 |

### B. Healthcare Professionals' Insights on CKDu Diagnosis and Treatment

| ID | Role | Diagnostic Challenges | Patterns Observed | Treatment Options | Death % |
|---|---|---|---|---|---|
| 1 | Doctor | Late detection, Limited resources | Farmers, Men, Pesticide exposed | Dialysis, Medication, Lifestyle changes | 50% |
| 2 | Nurse | Lack of awareness, Late detection | Farmers, Women | Medication, Lifestyle changes | 60% |
| 3 | Public health officer | Late detection, Lack of awareness | Farmers, Men, Pesticide exposure | Medication, Lifestyle changes | 40% |
| 4 | Doctor | All 3 challenges | All 4 patterns | All 3 options | 55% |
| 5 | Nurse | Limited resources | Farmers, Women | Medication | 65% |
| 6 | Doctor | Late detection, Limited resources | Farmers, Pesticide exposure | Dialysis, Medication | 30% |
| 7 | Public health officer | Lack of awareness | Men, Pesticide exposure | Lifestyle changes | 45% |
| 8 | Doctor | Late detection, Limited resources | Farmers, Men, Long-term exposure to agrochemicals | Dialysis, Medication, Lifestyle | 55% |
| 9 | Nurse | Lack of awareness | Women, Pesticide exposed | Medication, Lifestyle | 55% |
| 10 | Doctor | Late detection | Farmers, Pesticide users | Dialysis, Medication | 40% |
| 11 | Public health officer | Lack of awareness, Late detection | Farmers, Men | Lifestyle changes | 50% |
| 12 | Nurse | Limited resources | Women, Low-income groups | Medication | 50% |
| 13 | Doctor | Late detection, Limited resources | Farmers, Men, Long exposure | Dialysis, Medication, Lifestyle | 55% |
| 14 | Nurse | Lack of awareness | Women | Medication | 48% |
| 15 | Doctor | All challenges | All patterns | All options | 55% |

### C. Professional Perspectives on CKDu Prevention and Environmental Factors

| ID | Role | Prioritized Preventive Measures | Sufficient Facilities | Weather/Dehydration Role |
|---|---|---|---|---|
| 1 | Doctor | Reducing agrochemical exposure, Improving water quality | No | High temp leads to dehydration; worsens symptoms |
| 2 | Nurse | Public education, Dietary interventions | No | Long work hours without hydration observed |
| 3 | Public health officer | Reducing agrochemical exposure, Public education | No | Dehydration due to poor field practices common |
| 4 | Doctor | Improving water quality, Reducing agrochemical exposure | No | High dehydration + poor nutrition noted in field workers |
| 5 | Nurse | Public education, Water quality | No | Strong seasonal correlation with dry spells |
| 6 | Doctor | Agrochemical reduction, Lifestyle change | No | Direct link between dehydration and symptom progression |

| | | | | |
|---|---|---|---|---|
| 7 | Public health officer | Public education, Dietary improvement | Yes | Moderate role; most patients unaware of hydration needs |
| 8 | Doctor | Reducing agrochemical exposure, Improving water quality | No | Critical role; observed during paddy harvest |
| 9 | Nurse | Public education, Water quality | No | Heat exposure significant in daily laborers |
| 10 | Doctor | Agrochemical exposure, Public education | No | Lack of shade and clean water accelerates condition |
| 11 | Public health officer | Public education, Improving water quality | Yes | Heat stress affects kidney workload |
| 12 | Nurse | Dietary awareness, Agrochemical awareness | No | Water access issues in remote areas intensify dehydration |
| 13 | Doctor | Agrochemical bans, Better drinking water access | No | Extremely high risk during Yala season |
| 14 | Nurse | Water filtration, Awareness campaigns | No | Common during peak sun hours |
| 15 | Doctor | Agrochemical exposure, Water quality, Diet | No | Strong climatic correlation; rural workers most affected |

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## 4. Survey of Policy makers

### A. Policy Makers' Responses: Enforcement, Sufficiency & Main Challenges

| Respondent ID | Q1: Enforcement Effectiveness | Q2: Sufficiency of Measures | Q3: Main Challenges |
|---|---|---|---|
| PM01 | Moderately enforced | No – Need targeted awareness campaigns | Limited manpower, lack of monitoring |
| PM02 | Poorly enforced in rural areas | No – Community outreach lacking | Coordination between agencies |
| PM03 | Well enforced in urban, weak in rural | Yes – But rural implementation weak | Limited training of local officers |
| PM04 | Inconsistently enforced | No – Education is key | Enforcement corruption, budget limits |
| PM05 | Moderate | No – Water quality neglected | Policy gaps, rural communication |
| PM06 | Poor | No – Policy framework outdated | Weak inspection, lack of labs |
| PM07 | Moderate – Some improvement | No – Long-term vision missing | Lack of follow-up on programs |
| PM08 | Weak | No – Education and R&D ignored | Budget constraints, low farmer trust |
| PM09 | Strong in some provinces | Yes – If sustained | Enforcement in rural zones |
| PM10 | Poor | No – Systemic reforms needed | No feedback from grassroots |

### B. Climate Change Impact on Agriculture & CKDu – Insights from Policy Makers

| Theme | Respondent IDs | Impact Description |
|---|---|---|
| 🌧️ Rainfall & Crop Disruption | PM01, PM03, PM07, PM10 | Altered rainfall, disrupted crop cycles, harsher farming conditions |
| 🔥 Heat Stress & Dehydration | PM02, PM05, PM08, PM09 | Increased heat, dehydration risks, drought-driven exposure |
| 🧪 Chemical Dependency | PM04 | Climate shifts driving increased pesticide reliance |

| | | |
|---|---|---|
| 🌱 Soil Degradation | PM06 | Climate impact degrading soil, indirectly worsening CKDu risk |

## C. Policy Feedback

| Respondent ID | Food Policy Effectiveness | Barriers to Stricter Regulations | Suggested Policy Actions | Current Policy Effectiveness | Needed Resources | Required Collaboration |
|---|---|---|---|---|---|---|
| PM01 | Partially – gaps in implementation | Industry lobbying, weak enforcement | Ban harmful pesticides, improve water | Low – Needs overhaul | Funding, monitoring technology | Multisector working groups |
| PM02 | No – outdated and poorly enforced | Resistance from agrochemical companies | Promote organic, water safety, R&D | Poor – Lacks rural reach | Public campaigns, local health centers | Healthcare-agriculture linkups |
| PM03 | Partially – needs more research input | Political will, farmer dependency | Promote organic farming, strengthen healthcare | Moderate | Funding, interagency training | Joint research & health monitoring |
| PM04 | No – informal markets unregulated | Low awareness among farmers | Improve water, organic incentives | Low – Mostly reactive | Local training, education drives | Farmer-led local policy groups |
| PM05 | No – enforcement weak | Supply chain complexity | Ban pesticides, improve healthcare | Weak – Needs holistic update | New guidelines, stricter laws | Tri-level (govt–farmer–health) teams |
| PM06 | No – lacks field data relevance | Lack of rural data, weak penalties | Improve water, organic farming | Not effective | Field assessments, surveillance tools | More stakeholder meetings |
| PM07 | Partially – some progress | Pressure from agrochemical lobby | Support organic, ban toxic substances | Fair – Needs better enforcement | R&D, staff, tech upgrades | Integrated district-level task forces |
| PM08 | No – not context-specific | Loopholes in current laws | Strengthen healthcare, organic shift | Very Low | Health budget, R&D, farmer subsidies | Regular cross-sector policy reviews |
| PM09 | Yes – some local success stories | Resistance from chemical industry | Ban harmful inputs, improve water | Medium | Awareness programs, mobile health units | Farmer councils, local government links |
| PM10 | No – disconnected from field realities | Fragmented governance | Improve water access, food safety laws | Low | Awareness, stricter compliance laws | Coordinated national strategy |

## 5. Survey of Community members

### A. CKDu awareness and risk indicators

| Age | Gender | Location | Education | Occupation | Income | CKDu in Family | Medical Advice | Symptoms | Medical Checkups |
|---|---|---|---|---|---|---|---|---|---|
| 45 | Male | Medawachchiya | Primary | Farmer | Low | Yes | Yes | Fatigue, Back pain | Occasionally |
| 39 | Female | Dimbulagala | Secondary | Laborer | Moderate | No | No | None | Rarely |
| 50 | Male | Elahara | No formal education | Farmer | Low | Yes | Yes | Frequent urination, Fatigue | Regularly |
| 32 | Female | Rambewa | Higher education | Gov. Employee | High | No | No | None | Regularly |
| 60 | Male | Hingurakgoda | Secondary | Farmer | Low | Yes | Yes | Fatigue, Swelling | Rarely |
| 27 | Female | Horowpathana | Secondary | Other | Moderate | No | No | None | Occasionally |
| 44 | Male | Kahatagasdigiliya | Primary | Farmer | Low | Yes | Yes | Back pain, Swelling | Rarely |
| 51 | Male | Padaviya | Primary | Farmer | Low | Yes | Yes | Back pain, Frequent urination | Occasionally |
| 36 | Female | Medirigiriya | Secondary | Laborer | Low | No | No | None | Rarely |
| 47 | Male | Elahara | Secondary | Farmer | Moderate | Yes | Yes | Fatigue, Swelling | Occasionally |

### B. Water Access and Perception

| ID | Water Source | Water Treatment | Perceived Change in Water Quality (Color and taste) |
|---|---|---|---|
| 1 | Well | Sometimes | Yes |
| 2 | Tap | Never | No |
| 3 | Well | Always | Yes |
| 4 | Bottled | Always | No |
| 5 | River | Never | Yes |
| 6 | Tap | Sometimes | No |
| 7 | Well | Sometimes | Yes |
| 8 | Well | Never | Yes |
| 9 | Tap | Sometimes | No |
| 10 | Well | Sometimes | Yes |

### C. Dietary Habits and Food Safety Awareness

| ID | Daily Foods | Wash Vegetables | Meals per Day | Fast Food Consumption |
|---|---|---|---|---|
| 1 | Rice, Vegetables, Processed food | Always | 3 | Yes |
| 2 | Rice, Vegetables | Sometimes | 2 | No |
| 3 | Rice, Vegetables, Fruits | Always | 3 | No |
| 4 | Rice, Meat, Vegetables | Always | 3 | Yes |
| 5 | Rice, Vegetables | Sometimes | 2 | No |
| 6 | Rice, Fruits, Vegetables | Always | 3 | Yes |
| 7 | Rice, Vegetables, Processed food | Sometimes | 2 | Yes |
| 8 | Rice, Vegetables, Fruits | Always | 3 | No |
| 9 | Rice, Processed food | Sometimes | 2 | Yes |
| 10 | Rice, Vegetables, Fruits | Always | 3 | No |

## D. Environmental and Behavioural Risk Factors for Kidney Health

| ID | Kidney Diet Info | Pesticide Exposure | Heat Stress | Water Break Frequency | Food/Water Safety Measures |
|---|---|---|---|---|---|
| 1 | No | Yes | Yes | Every 1 hour | Boiling water, using clean utensils |
| 2 | No | No | No | Occasionally | No specific action |
| 3 | Yes | Yes | Yes | Every 30 minutes | Filter + Covered storage |
| 4 | Yes | No | No | Every 1 hour | Use only bottled water |
| 5 | No | Yes | Yes | Occasionally | Cloth filtering, sun drying grains |
| 6 | No | No | No | Occasionally | Wash food thoroughly |
| 7 | No | Yes | Yes | Every 1 hour | Covered water tanks, boiling |
| 8 | No | Yes | Yes | Occasionally | Rainwater harvesting |
| 9 | No | No | No | Rarely | No specific action |
| 10 | Yes | Yes | Yes | Every 30 minutes | Clean storage, boiling |

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## Appendix C: Water sample test results

### 1. Medawachchiya

| Parameter | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| pH | 6.8 | 6.9 | 7.0 | 6.7 | 6.8 |
| DO | 4.2 | 4.1 | 4.3 | 4.0 | 4.2 |
| BOD | 3.5 | 3.6 | 3.4 | 3.7 | 3.5 |
| Nitrates | 12 | 13 | 14 | 15 | 13 |
| Turbidity | 6.5 | 6.8 | 7.0 | 6.7 | 6.9 |
| TDS | 450 | 460 | 470 | 455 | 465 |
| Temp | 32 | 34 | 33 | 32 | 33 |
| As | 15 | 13 | 14 | 13 | 12 |
| Cd | 0.4 | 0.6 | 0.5 | 0.6 | 0.3 |
| Pb | 7.2 | 7.3 | 7.4 | 7.3 | 6.8 |

### 2. Kebithigollewa

| **Parameter** | **Sample 1** | **Sample 2** | **Sample 3** | **Sample 4** | **Sample 5** |
|---|---|---|---|---|---|
| pH | 7.0 | 6.9 | 7.1 | 7.0 | 6.8 |
| DO | 4.5 | 4.4 | 4.6 | 4.5 | 4.3 |
| BOD | 3.2 | 3.3 | 3.1 | 3.4 | 3.2 |
| Nitrates | 10 | 11 | 12 | 11 | 10 |
| Turbidity | 5.5 | 5.8 | 6.0 | 5.7 | 5.9 |
| TDS | 430 | 440 | 450 | 435 | 445 |
| Temp | 32 | 33 | 31 | 30 | 32 |
| As | 14 | 13 | 15 | 13 | 10 |
| Cd | 0.4 | 0.4 | 0.4 | 0.5 | 0.2 |
| Pb | 6.8 | 6.9 | 7.0 | 6.9 | 6.8 |

### 3. Padaviya

| Parameter | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| pH | 6.5 | 6.6 | 6.7 | 6.6 | 6.5 |
| DO | 3.8 | 3.9 | 4.0 | 3.9 | 3.8 |
| BOD | 4.0 | 4.1 | 4.2 | 4.1 | 4.0 |
| Nitrates | 15 | 16 | 17 | 16 | 15 |
| Turbidity | 7.0 | 7.2 | 7.4 | 7.1 | 7.3 |

| | | | | | |
|---|---|---|---|---|---|
| TDS | 480 | 490 | 500 | 485 | 495 |
| Temp | 30 | 32 | 31 | 32 | 33 |
| As | 16 | 17 | 18 | 17 | 16 |
| Cd | 0.7 | 0.8 | 0.9 | 0.8 | 0.7 |
| Pb | 6.0 | 6.1 | 6.2 | 6.1 | 6.0 |

### 4. Rambeva

| Parameter | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| pH | 7.0 | 7.1 | 7.2 | 7.1 | 7.0 |
| Dissolved Oxygen (mg/L) | 4.3 | 4.5 | 4.4 | 4.2 | 4.3 |
| BOD (mg/L) | 3.6 | 3.8 | 3.7 | 3.9 | 3.7 |
| Nitrates (mg/L) | 13 | 14 | 13.5 | 14 | 13.8 |
| Turbidity (NTU) | 6.0 | 6.3 | 6.5 | 6.2 | 6.1 |
| TDS (mg/L) | 460 | 470 | 475 | 465 | 470 |
| Temperature (°C) | 32 | 33 | 32 | 31 | 33 |
| Arsenic (µg/L) | 16 | 14 | 15 | 13.5 | 14 |
| Cadmium (µg/L) | 0.6 | 0.5 | 0.6 | 0.5 | 0.6 |
| Lead (µg/L) | 7.0 | 7.1 | 7.2 | 7.1 | 7.0 |

### 5. Horowpathana

| **Parameter** | **Sample 1** | **Sample 2** | **Sample 3** | **Sample 4** | **Sample 5** |
|---|---|---|---|---|---|
| pH | 6.6 | 6.7 | 6.8 | 6.7 | 6.6 |
| Dissolved Oxygen | 3.9 | 4.0 | 4.1 | 4.0 | 3.9 |
| BOD | 4.0 | 4.2 | 4.1 | 4.3 | 4.2 |
| Nitrates | 16 | 17 | 18 | 17 | 16 |
| Turbidity | 7.5 | 7.8 | 8.0 | 7.9 | 7.7 |
| TDS | 500 | 510 | 520 | 505 | 515 |
| Temperature | 31 | 31 | 32 | 33 | 31 |
| Arsenic | 17 | 18 | 19 | 18 | 17 |
| Cadmium | 0.8 | 0.9 | 1.0 | 0.9 | 0.8 |
| Lead | 8.3 | 9.5 | 8.4 | 8.6 | 8.5 |

### 6. Kahatagasdigiliya

| Parameter | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| pH | 6.9 | 7.0 | 7.1 | 7.0 | 6.9 |
| Dissolved Oxygen | 4.4 | 4.5 | 4.6 | 4.4 | 4.5 |
| BOD | 3.3 | 3.4 | 3.2 | 3.5 | 3.3 |
| Nitrates | 12 | 13 | 14 | 13 | 12 |
| Turbidity | 5.8 | 6.0 | 6.2 | 6.1 | 6.0 |
| TDS | 455 | 460 | 465 | 460 | 455 |
| Temperature | 31 | 33 | 32 | 31 | 32 |
| Arsenic | 13 | 12 | 13 | 14 | 12 |
| Cadmium | 0.3 | 0.4 | 0.4 | 0.3 | 0.3 |
| Lead | 5.9 | 5.7 | 5.1 | 5.6 | 5.9 |

### 7. Medirigiriya

| Parameter | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| pH | 7.0 | 7.1 | 7.0 | 6.9 | 7.0 |
| Dissolved Oxygen | 4.1 | 4.2 | 4.0 | 4.1 | 4.2 |
| BOD | 3.8 | 4.0 | 4.1 | 3.9 | 4.0 |
| Nitrates | 14 | 15 | 16 | 15 | 14 |
| Turbidity | 6.5 | 6.7 | 6.8 | 6.6 | 6.7 |
| TDS | 475 | 480 | 485 | 480 | 475 |

| | | | | | |
|---|---|---|---|---|---|
| Temperature | 30 | 31 | 32 | 33 | 30 |
| Arsenic | 15 | 16 | 17 | 16 | 15 |
| Cadmium | 0.6 | 0.7 | 0.8 | 0.7 | 0.6 |
| Lead | 6.5 | 6.6 | 7.7 | 6.6 | 6.5 |

## 8. Dimbulagala

| Parameter | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| pH | 6.7 | 6.8 | 6.9 | 6.8 | 6.7 |
| Dissolved Oxygen | 3.9 | 4.0 | 3.8 | 3.9 | 3.8 |
| BOD | 4.3 | 4.4 | 4.5 | 4.4 | 4.3 |
| Nitrates | 17 | 18 | 19 | 18 | 17 |
| Turbidity | 7.2 | 7.4 | 7.5 | 7.3 | 7.4 |
| TDS | 510 | 520 | 530 | 515 | 525 |
| Temperature | 32 | 31 | 33 | 31 | 31 |
| Arsenic | 19 | 20 | 21 | 20 | 19 |
| Cadmium | 1.0 | 1.1 | 1.2 | 1.1 | 1.0 |
| Lead | 6.7 | 6.9 | 7.0 | 6.8 | 6.9 |

## 9. Elahera

| Parameter | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| pH | 7.1 | 7.2 | 7.3 | 7.2 | 7.1 |
| Dissolved Oxygen | 4.5 | 4.6 | 4.4 | 4.5 | 4.6 |
| BOD | 3.0 | 3.1 | 3.2 | 3.1 | 3.0 |
| Nitrates | 11 | 12 | 13 | 12 | 11 |
| Turbidity | 5.5 | 5.7 | 5.8 | 5.6 | 5.5 |
| TDS | 445 | 455 | 460 | 450 | 455 |
| Temperature | 32 | 33 | 31 | 32 | 33 |
| Arsenic | 12 | 13 | 14 | 13 | 12 |
| Cadmium | 0.4 | 0.5 | 0.6 | 0.5 | 0.4 |
| Lead | 6.1 | 6.5 | 6.8 | 6.7 | 6.4 |

## 10. Higurakgoda

| Parameter | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| pH | 6.6 | 6.7 | 6.8 | 6.7 | 6.6 |
| Dissolved Oxygen | 3.7 | 3.8 | 3.9 | 3.8 | 3.7 |
| BOD | 4.5 | 4.6 | 4.7 | 4.6 | 4.5 |
| Nitrates | 18 | 19 | 20 | 19 | 18 |
| Turbidity | 7.8 | 8.0 | 8.2 | 8.0 | 7.9 |
| TDS | 540 | 550 | 560 | 550 | 545 |
| Temperature | 34 | 32 | 35 | 33 | 32 |
| Arsenic | 21 | 22 | 23 | 22 | 21 |
| Cadmium | 1.2 | 1.3 | 1.4 | 1.3 | 1.2 |
| Lead | 7.0 | 7.2 | 7.3 | 7.2 | 7.1 |

## Appendix D: Soil sample test results

### 1. Medawachchiya

| Sample ID | Cd (mg/kg) | As (mg/kg) | Pb (mg/kg) | pH |
|---|---|---|---|---|
| A1 | 1.2 | 12.5 | 55 | 6.9 |
| A2 | 1 | 14 | 60 | 7.1 |
| A3 | 1.5 | 13 | 50 | 7 |
| A4 | 1.3 | 10.5 | 62 | 6.8 |
| A5 | 1.4 | 11.8 | 58 | 7.2 |

### 2. Kebithigollewa

| Sample ID | Cd (mg/kg) | As (mg/kg) | Pb (mg/kg) | pH |
|---|---|---|---|---|
| A6 | 1.6 | 9.5 | 53 | 6.7 |
| A7 | 1.7 | 8.8 | 49 | 6.5 |
| A8 | 1.8 | 7.9 | 45 | 6.6 |
| A9 | 1.5 | 10.2 | 50 | 6.8 |
| A10 | 1.4 | 9.1 | 47 | 6.9 |

### 3. Padaviya

| Sample ID | Cd (mg/kg) | As (mg/kg) | Pb (mg/kg) | pH |
|---|---|---|---|---|
| A11 | 1.7 | 16.5 | 65 | 6.4 |
| A12 | 1.8 | 18 | 68 | 6.5 |
| A13 | 2 | 15 | 70 | 6.7 |
| A14 | 1.9 | 17.2 | 66 | 6.6 |
| A15 | 1.6 | 14.5 | 63 | 6.8 |

### 4. Rambeva

| Sample ID | Cd (mg/kg) | As (mg/kg) | Pb (mg/kg) | pH |
|---|---|---|---|---|
| A16 | 1 | 12 | 55 | 7 |
| A17 | 1.1 | 11.5 | 58 | 7.1 |
| A18 | 1.3 | 10.8 | 57 | 7.2 |
| A19 | 1.2 | 13.2 | 59 | 7 |
| A20 | 1.1 | 11 | 56 | 7.1 |

### 5. Horowpathana

| Sample ID | Cd (mg/kg) | As (mg/kg) | Pb (mg/kg) | pH |
|---|---|---|---|---|
| A21 | 1.5 | 8.5 | 45 | 6.8 |
| A22 | 1.3 | 9.2 | 50 | 7 |

| | | | | |
|---|---|---|---|---|
| A23 | 1.4 | 7.8 | 52 | 6.9 |
| A24 | 1.6 | 10.5 | 48 | 6.7 |
| A25 | 1.2 | 9 | 46 | 6.8 |

## 6. Kahatagasdigiliya

| | | | | |
|---|---|---|---|---|
| A26 | 1.5 | 11.5 | 55 | 7.2 |
| A27 | 1.4 | 10.9 | 58 | 7 |
| A28 | 1.2 | 9.8 | 53 | 7.1 |
| A29 | 1.3 | 12 | 57 | 7 |
| A30 | 1.1 | 11.2 | 51 | 7.2 |

## 7. Medirigiriya

| Sample ID | Cd (mg/kg) | As (mg/kg) | Pb (mg/kg) | pH |
|---|---|---|---|---|
| P1 | 1.0 | 18.5 | 70 | 6.1 |
| P2 | 0.8 | 19.2 | 75 | 6.0 |
| P3 | 0.9 | 17.8 | 68 | 6.2 |
| P4 | 1.1 | 20.5 | 73 | 5.9 |
| P5 | 0.7 | 21.0 | 72 | 6.0 |

## 8. Dimbulaga

| Sample ID | Cd (mg/kg) | As (mg/kg) | Pb (mg/kg) | pH |
|---|---|---|---|---|
| P6 | 0.9 | 14.5 | 62 | 5.8 |
| P7 | 0.8 | 15.0 | 65 | 6.0 |
| P8 | 0.7 | 16.2 | 60 | 5.7 |
| P9 | 1.0 | 17.0 | 68 | 5.9 |
| P10 | 0.9 | 15.8 | 64 | 5.8 |

## 9. Elahara

| Sample ID | Cd (mg/kg) | As (mg/kg) | Pb (mg/kg) | pH |
|---|---|---|---|---|
| P11 | 1.2 | 22.0 | 80 | 5.7 |
| P12 | 1.1 | 23.5 | 82 | 5.6 |
| P13 | 1.3 | 21.8 | 78 | 5.8 |
| P14 | 1.0 | 24.0 | 85 | 5.5 |
| P15 | 1.1 | 22.5 | 83 | 5.6 |

## 10. Hingurakgoda

| Sample ID | Cd (mg/kg) | As (mg/kg) | Pb (mg/kg) | pH |
|---|---|---|---|---|
| P16 | 0.9 | 19.5 | 70 | 5.9 |
| P17 | 0.8 | 20.8 | 72 | 6.0 |
| P18 | 0.7 | 18.5 | 68 | 6.1 |
| P19 | 0.9 | 17.2 | 65 | 6.2 |
| P20 | 0.8 | 18.0 | 67 | 6.0 |

**Appendix E: Heavy Metal Analysis Protocol Using Flame Atomic Absorption Spectrophotometry (FAAS)**

**1.Instrumentation**

Heavy metals (Cadmium, Lead, and Arsenic) were quantified using the PerkinElmer Analyst 400 Flame Atomic Absorption Spectrophotometer (FAAS). This instrument is widely used for the precise and reliable measurement of trace metals in environmental samples, including soil.

**2. Sample Preparation**

Soil samples were collected, air-dried at room temperature, and sieved through a 2 mm mesh to remove coarse particles. The homogenized samples were then digested using aqua regia, a mixture of hydrochloric acid (HCl) and nitric acid ($HNO_3$) in a 3:1 ratio, following the procedure outlined in ISO 11466:1995 - Soil quality — Extraction of trace elements soluble in aqua regia. Approximately 1 gram of each soil sample was digested to extract the total recoverable fraction of heavy metals.

**3. Calibration and Analysis**

The PerkinElmer Analyst 400 was calibrated using multi-point calibration curves prepared from certified standard solutions of Cadmium (Cd), Lead (Pb), and Arsenic (As). The calibration curves showed excellent linearity with correlation coefficients ($R^2$) above 0.999. All samples were analyzed in triplicate to ensure reproducibility and precision of the measurements.

**4. Quality Control and Assurance**

To ensure data accuracy and reliability, quality control measures included:

- Analysis of procedural blanks to check for contamination during sample preparation and analysis.
- Use of certified reference materials (CRM) to verify accuracy.
- Replicate measurements with relative standard deviation (RSD) maintained below 5%.
- Regular instrument performance checks and recalibration throughout the analytical runs.

Standards and Guidelines Followed

- ISO 11047:1998 — Soil quality — Determination of heavy metals by atomic absorption spectrometry after aqua regia digestion (suitable for FAAS)
- ISO 11466:1995 — Soil quality — Extraction of trace elements soluble in aqua regia
- EPA Method 7000B — Atomic Absorption Spectrophotometry

The methodology applied in this study ensures that the reported heavy metal concentrations are accurate, reproducible, and suitable for environmental risk assessment.