

**Farming Practices and Implications for Water Quality and Sustainability at S'ang, Kandal,  
Cambodia**

**Bunneam Chhimcanal**

Master's of Environmental Management

Department of Natural Resources and Environmental Management

University of Hawai'i at Mānoa

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Capstone Panel:

Dr. Yinphan Tsang (NREM Advisor)

Dr. Creighton M. Litton (Course Instructor)

Dr. Subhashni Raj (3<sup>rd</sup> Panel Member)

## Abstract

In Cambodia, the primary water issue is the pollution of surface water by organic and inorganic pollutants linked to agricultural and non-agricultural activities. The objective of this study was to investigate the pressing issue of decreasing water quality linked to agricultural activities using cooperative methods to monitor water quality as influenced by farmer practices. Overall, the goal was to assess the relationship between agricultural runoff and sediment and nutrient levels in local water bodies. As such, this study analyzed the impacts of agricultural practices on water quality in S'ang, Kandal, Cambodia, focusing on farm irrigation, fertilizer application, and manure management via water quality testing, Geographical Information System (GIS) mapping, and qualitative insights from farmer interviews. There were three periods of water sampling, which commenced in May (dry season – with irrigation & fertilizer), August 2024 (wet season – rain-fed period with reduced fertilizer), and March 2025 (dry season – harvest & post-harvest period) to ensure the data captured the complete farming practice and management scenarios. Five farmers participated in the focus group interview. Water samples were analyzed in a laboratory, while Excel was used for data visualization and trend analysis. Nonnumerical Unstructured Data Indexing, Searching, and Theorizing software (NVIVO) facilitated qualitative analysis, identifying themes and patterns from interviews.

I found while most parameters such as total nitrogen (TN), total phosphorus (TP), total dissolved solids (TDS), total suspended solids (TSS), and chlorophyll remained within acceptable standards, potassium (K) and turbidity levels frequently exceeded thresholds, particularly during the dry season when fertilizer use and irrigation respectively were most intensive. These elevated K and turbidity levels suggested a strong link between seasonal farming practices and nutrient runoff, although potential contributions from domestic wastewater and industrial sources cannot be ruled out. This study underscored the long-term risks of unmanaged agricultural practices on water quality, potentially affecting both human and ecological health. Promoting best management practices, providing knowledge incentives for sustainable farming, and fostering community-led monitoring programs could help mitigate water contamination. This study provided a critical foundation for improving water resource management in Cambodia and similar agricultural regions globally.

**Keywords:** agricultural practices, land runoff, human welfare, water quality testing, sediments, nutrients, and stream water.

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## Motivation

There is a pressing need for a nuanced understanding of local factors influencing water quality that are linked to agricultural practices (Wardropper et al., 2015). Declining water quality directly threatens human health, primarily due to poorly controlled agricultural practices and untreated and unmonitored excessive nutrients and runoff. A projected 9.7 billion people on Earth in 2050 will result in a 20–30% rise in global water consumption of high-quality water (UNESCO, 2019). In 2020, China and India utilized vast nutrients (nitrate and phosphate) to enhance crop growth and yield, resulting in the highest nitrate and phosphate concentrations in groundwater globally (Ravindiran et al., 2023). High nitrate levels in drinking water can result in methemoglobinemia ("blue baby syndrome"), a potentially fatal illness in newborns (EPA, 2024). However, several intricate and interconnected issues, such as excessive groundwater extraction, extreme weather, sea level rise, industrial pollution, and overuse of pesticides and fertilizers, pose a growing threat to water quality and availability. The 2030 Agenda for Sustainable Development acknowledges water quality issues and provides a particular goal for improving water quality in Sustainable Development Goal 6 for Southeast Asia, including Cambodia (Sunam & Mahat, 2020). For example, rice-based agriculture in the Mekong Delta comprises over 65% of all freshwater demands (GWP, 2020).

The motivation for addressing water quality issues in Cambodia's agriculture is rooted in its far-reaching consequences for human welfare, ecosystem health, and the sustainability of water resources. The project addressed part of the complex challenges posed by agricultural practices on water quality by integrating environmental science and agriculture in S'ang, Kandal, Cambodia. Several stakeholders, managers, and decision-makers were involved in addressing the problem of declining water quality linked to agricultural practices in Cambodia. These included non-government agencies such as the East-West Center (EWC)'s researchers, environmental organizations, researchers, farmers, and regional agricultural authorities responsible for overseeing farming practices. The specific need regarding the water quality problem is to develop and implement effective mitigation strategies for agricultural practices that negatively impact water quality. Additionally, there is a need for increasing public awareness and education on the importance of adopting best practices among farmers and the broader community to address critical water quality issues. The interdisciplinary context of the project lies in the intersection of environmental science, public health, agriculture, and policy. An interdisciplinary approach is essential for developing comprehensive strategies to mitigate the adverse effects of agricultural activities on water quality while promoting sustainable practices that ensure water safety for human consumption and the environment.

## Background

Cambodia has significant water resources, with abundant surface water, aquifers, and high levels of seasonal rainfall (WAH, 2006). Groundwater serves as a lifeline for those who depend on it for drinking and daily household activities, while surface water is often harnessed for irrigation (Evensen, 2010). As Cambodia strives to increase local food production and expand its agricultural sector, concerns have arisen about the potential impact of farming practices on nearby water bodies (GIZ, 2020). While agriculture is dependent on reliable freshwater for irrigation, it can also pollute nearby waterways, threatening water sources for humans and overall ecological health (Delpasand et al., 2021). It is, therefore, imperative to investigate water quality in proximity to farms and to document agricultural practices that negatively influence water quality.

Prior studies have highlighted a suite of water contaminants at S'ang and emphasized the importance of agricultural practices as a potential cause for contamination. Existing literature has identified the challenges posed by inadequate agricultural practices on water quality (El-Swaify, 2002). A need for more research, specifically localized studies, exists to correlate changes in water quality near farms with evolving agricultural practices (Mair et al., 2013). This study is relevant to the Socio-Hydrology Framework, which is a conceptual model that integrates human and water system interactions, emphasizing feedback loops between human behaviors, policies, and hydrological processes (Elshafei et al., 2014). This framework particularly helps explain how agricultural practices, farmer decision-making, and environmental conditions collectively shape water resource sustainability. Planning land use and managing watersheds effectively depends on understanding the effects of different land use and land cover types on water quality, and how spatial and temporal scales contribute to these effects (De Mello et al., 2020). El-Swaify (2001) emphasized the importance of considering both ecological and social factors, but focused on broad water quality trends and overlooked the nuanced interplay between agricultural practices, farmer activities, and their specific impacts on nearby water bodies. Irrigation practices, especially in areas with dense farm concentrations, can lead to excess water runoff carrying fertilizers and pesticides into nearby water sources. Additionally, fertilizer usage, particularly when not properly managed, can result in nutrient leaching into groundwater and surface water systems (Amić & Tadić, 2018). Effective manure management is crucial as well, as improper handling can lead to nutrient-rich runoff contaminating water bodies, contributing to nutrient pollution and degraded water quality (EPA, 2023). By linking nutrient and sediment quality changes with changing farming practices such as irrigation, fertilizer, and manure management, this study sought to address current research gaps and provide guidance for agricultural land use planning techniques that effectively protect water quality.

## Objective

The primary objective of this project was to examine nutrient and sediment runoff near farms to document water quality as a function of farmer activities. This objective was met by sampling water quality and conducting focus group interviews, which together addressed three key questions: (i) What agriculture practices (e.g., use of fertilizers or manure management) are associated with declining water quality (e.g., excess nutrients)?; (ii) Does agricultural land runoff change the water quality of nearby streams via sedimentation?; and (iii) What are farmers' perceptions regarding enhancing water quality downstream from agriculture activities?

## Approach

### 1. Study Area

The study area for this project encompassed Teuk Vil commune, S'ang district, Kandal province, Cambodia, and specifically focused on the surface water systems within the Bassac River, which is a part of the Mekong River. S'ang district was chosen for its strong agricultural base and reliance on the Bassac River for irrigation, making it ideal for studying agriculture-water quality interactions. The fertile alluvial soil of the region enhances agricultural productivity, making the area ideal for growing diversified crops, with rice as the staple crop. S'ang district is 40 kilometers from the capital of Phnom Penh and is situated in the Kandal province. Approximately 85% of the district population is employed in farming, fishing, and animal husbandry. Other jobs include handicrafts (7%), officials (3%), and laborers (5%). The total area of 51,496 hectares contains 5,353 hectares of residential housing, 17,800.3 hectares of dry rice land, 6,122.6 hectares of wet rice land, 8,500 hectares of timber, and 13,720.1 hectares of other land (NCDD, 2012) & (Sopha et al., 2014). In addition to rice, farmers cultivate various fruits, vegetables, and other leaf crops, benefiting from the ample water supply and nutrient-rich soil. Overall, the geography of S'ang, characterized by its relationship with the Bassac River, underpins the district's agricultural economy and sustains the rural communities (ADB, 2012) (Figure 1). This area includes a dense concentration of large private farms proximate to the water sources, emphasizing the potential for interactions between agricultural activities and water quality.



**Figure 1.** Map of Cambodia highlighting provincial boundaries and a major river

## **2. Data Collection**

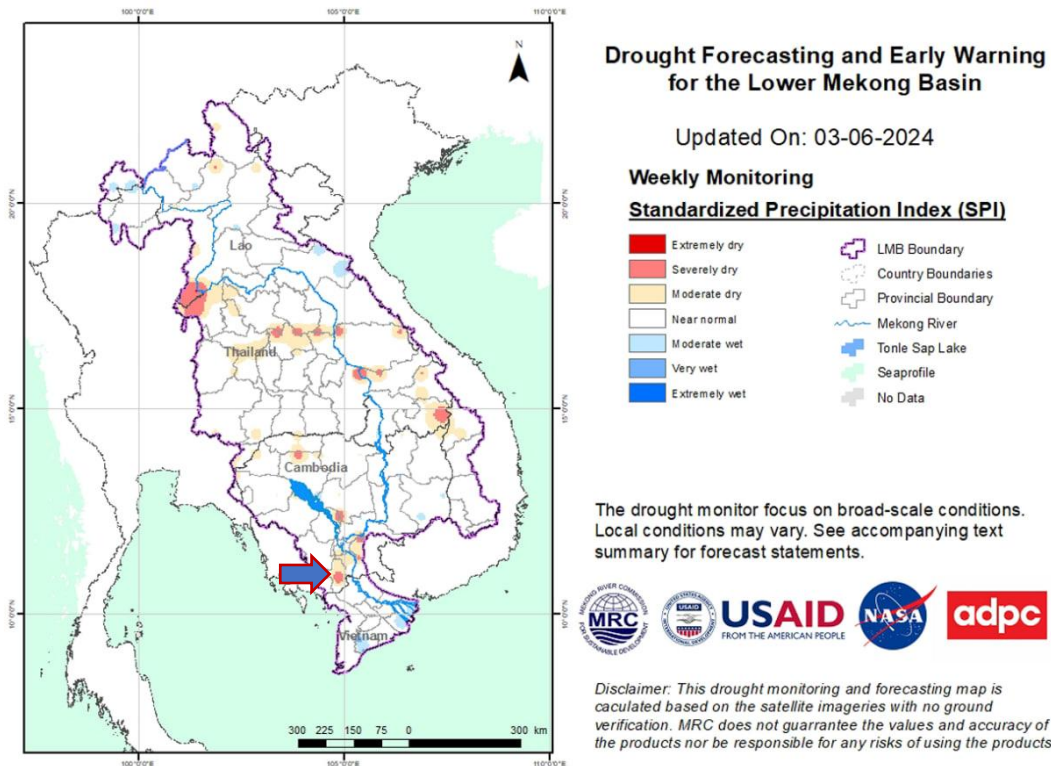
### ***Water Sampling***

Water quality sampling occurred at a 1.5-hectare farm in front of the Bassac River, where the farm used groundwater as a main water source for irrigation. There were three points of water sampling: Bassac River's upstream and downstream, and one well within the farm to assess the exact water quality from the farms (Figure 2). The project focused on three main agricultural practices due to their significant impact on stream water quality: irrigation, fertilizer usage, and manure management. The approach for water sampling was divided into the dry season with irrigation, the rainy season without irrigation, and the dry season with ceased irrigation. The wet season traditionally spans from approximately May through November, while December through April constitutes the dry season (Chhinh & Millington, 2015). However, due to climate change, the dry season has become increasingly unstable (UNDP, 2020). Based on rainfall data by the Mekong River Commission 2024, drought conditions persisted from the end of May to the beginning of June in Kandal province, so it was still considered part of the dry season for the samples taken in May 2024, for this study (Figure 3). Water sampling commenced in May 2024 (dry season – irrigation & fertilizer), August 2024 (rainy season – rain-fed and reduced fertilizer), and March 2025 (dry season – harvest & post-harvest) (Figures 4 & 5). Each sampling period tested nutrients and sediment, tailored to the three primary agricultural practices: irrigation, fertilizer usage, and manure management. Consequently, there were nine water sampling events throughout the designated period (3 times at each point). Water samplings were not aligned with any specific crop types, as the farmer's crop selection was influenced by factors such as market demand, agricultural preferences, and soil quality. Crops included corn, cabbage, green onion, lettuce, papaya, and onion. Utilizing water quality testing, the project analyzed various contaminants including nutrient parameters (i.e., Total nitrogen TN, Total phosphorus TP, Potassium K, Chlorophyll, Total organic carbon TOC, and Organic matter OM), sediments' parameters (i.e., Total suspended solids TSS, Total dissolved solids TDS, and Turbidity), and water chemistry (i.e., pH, Dissolved oxygen DO, Arsenic, and Electric conductivity EC). These contaminants can significantly affect environmental and human well-being: nutrient buildup can harm ecosystems and pose risks to human health if drinking water is not filtered; sediment indicators can degrade aquatic habitats and reduce environmental quality; and elevated EC, linked to salinity, can negatively impact crop yields.

## Water Sampling at S'ang, Kandal, Cambodia



**Figure 2.** Spatial map from GIS of water sampling at S'ang, Kandal, Cambodia



**Figure 3.** Weekly drought forecasting and early warning map for the lower Mekong basin on June 03, 2024



Up-stream point



Up-stream point



Down-stream point



Down-stream point



Wellpoint



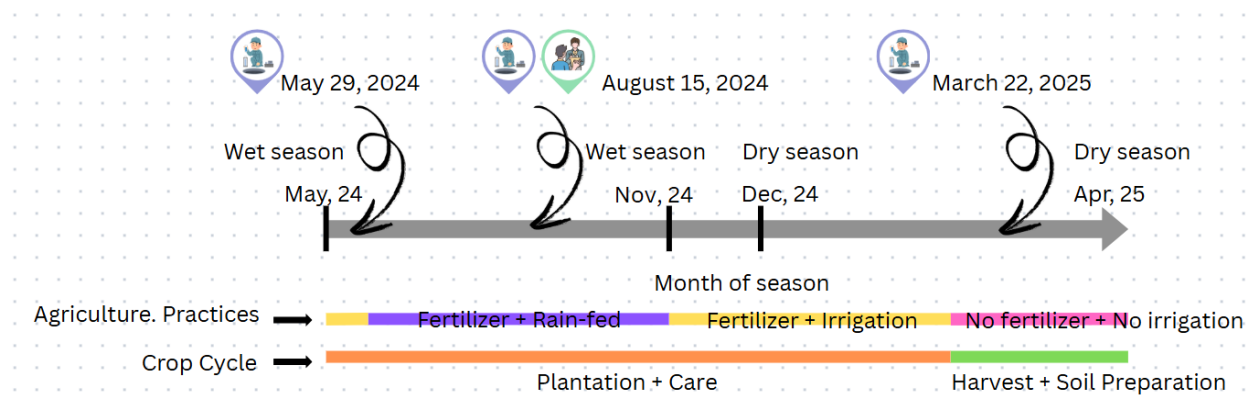
Wellpoint

**Figure 4.** Three water sampling points are at Teuk Vil commune, S'ang district, and Kandal province

**May 29, 2024 (Dry Season - Irrigation and Fertilization):** This phase marked active crop growth with frequent irrigation and fertilization. Testing assessed fertilizer runoff and sediment transport, while high evaporation rates concentrate pollutants, affecting TDS and turbidity.

**August 15, 2024 (Wet Season - Rain-fed and Reduced Fertilizer):** Water samples were taken to examine how rainfall influences nutrient leaching and contaminant dilution. Reduced irrigation and fertilization highlight rainfall's role in nutrient transport, soil erosion, and DO changes.

**March 22, 2025 (Dry Season - Harvest and Soil Preparation):** This phase focused on tilling and residue decomposition impacts on water quality. The absence of irrigation and fertilization provided a baseline to assess agricultural impacts over the full cycle.



**Figure 5.** Seasonal timeline of agricultural practices and plantation cycle (2024–2025)

### ***Focus Group Interview***

Five farmers were recruited with the assistance of local authorities based on their availability and proximity to the Bassac River (Figure 6). These farmers rely on groundwater for irrigation and represent fertilizer within the study area. The selected sample size was intentionally small, allowing for an in-depth exploration of individual experiences and practices while maintaining manageability for the qualitative data analysis. The interviews focused on three key areas: Basic Information (participants provided demographic data, information about their farming operations, the geographical layout of their farms, and details about the types of crops they cultivate), Exploration of Agricultural Practices (the main portion of the interview delved into the methods employed in irrigation, fertilizer usage, and manure management), and Perceptions of Water Quality and Recommendations (the final segment gathered the farmers' perspectives on current water quality issues).

Analyzing semi-structured focus group interview data involved transcribing the interviews, coding the data in NVIVO to identify themes and patterns, and conducting thematic analysis to interpret the findings (Blandford, 2013). The study employed thematic analysis with a deductive process as the primary method for qualitative data interpretation to systematically identify and analyze patterns within the data based on predetermined themes aligned with the

research questions (Vaismoradi et al., 2013). Predefined themes, such as "irrigation practices," "fertilizer use," and "manure management," were based on the study's objectives.



**Figure 6.** Focus group interview between local farmers and the Cambodian team in the commune hall at S'ang district, Kandal province, Cambodia

## Results

### 1. Water Quality Testing

#### *Seasonal Variations in Water Quality*

May 29, 2024 (Dry Season - Irrigation and Fertilization) sampling demonstrated that pH, TN, TP, TDS, TSS, DO, and chlorophyll levels were within the acceptable water quality standards, indicating no immediate concerns regarding these parameters (Table 1 & Figure 7). However, downstream turbidity, TOC, and K levels exceeded recommended thresholds as stream water flowed through the farm area. The exceedances were likely due to irrigation-induced soil erosion and fertilizer runoff, respectively (Stokes, 2023). However, the exceeded K levels upstream indicated the contribution of domestic pollution to water contamination (Wyatt et al., 2019). Upstream areas are located near densely populated or urbanized areas, domestic pollution, and nutrient-rich runoff from agricultural activities.

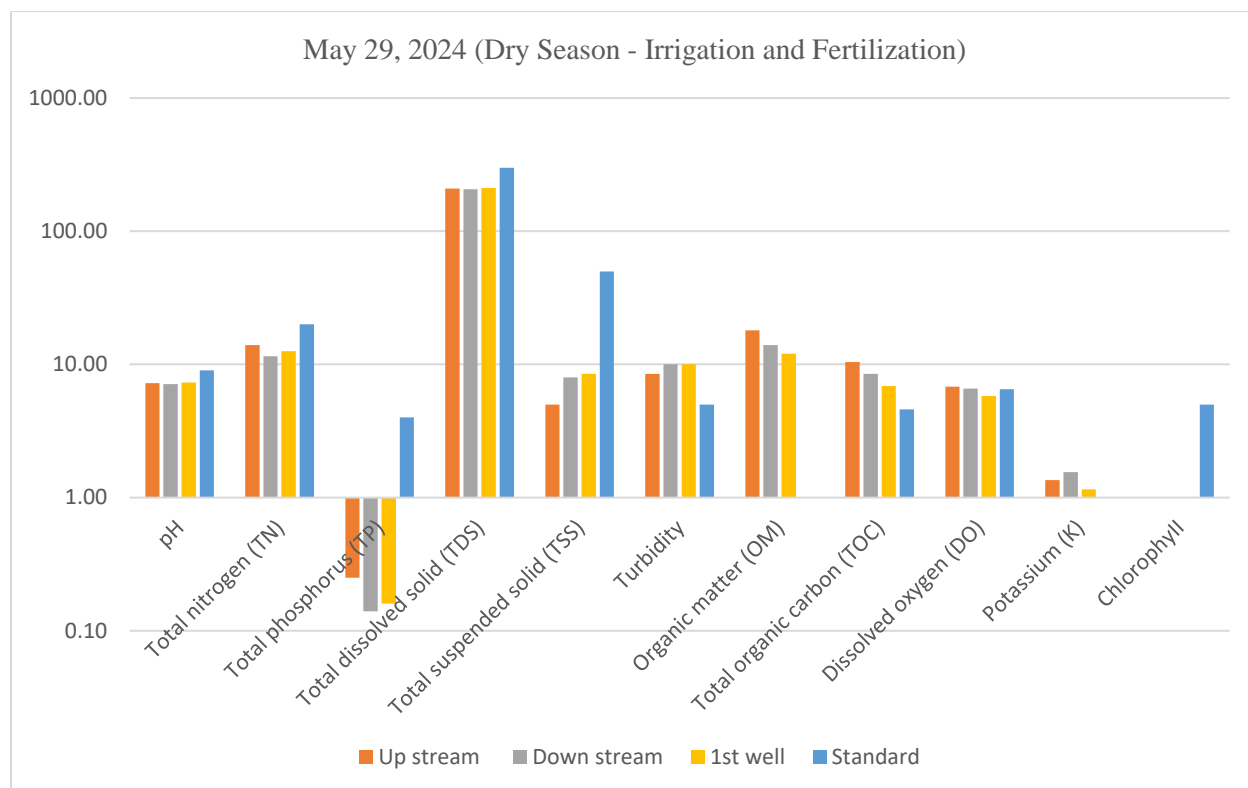
August 15, 2024 (Wet Season - Rain-fed and Reduced Fertilizer) sampling showed a reduction in the concentration of TN, TP, TSS, TDS, and chlorophyll (Table 2 & Figure 8), all of which stayed within regulatory water quality limits, indicating that rainfall-driven dilution and reduced fertilizer application had a positive effect on mitigating nutrient pollution (Kolochnik, 2008). However, K levels of the stream still exceeded the standard, indicating ongoing

contamination from many sources. This season, the stream flow was faster and at a higher level, potentially transporting various pollutants, including K, such as domestic wastewater, industrial effluents, nutrient runoff, and landfill leachate from upstream to downstream. The well showed higher EC during the wet season, likely due to increased leaching of salts and nutrients from agricultural soils. Rainfall infiltrates the soil, dissolved ions like nitrates, sulfates, and chlorides from fertilizers and manure, and carries them into the groundwater (USDA, 2011).

March 22, 2025 (Dry Season - Harvest and Soil Preparation) showed that TN, TP, TDS, TSS, and chlorophyll levels fell within acceptable water quality limits (Table 3 & Figure 9), indicating no concerns regarding nutrient pollution. K levels met the recommended water quality standards, marking an improvement compared to previous tests. This improvement likely occurred because the samplings were taken during harvest and soil preparation, when farmers were not applying fertilizers or irrigating. TP levels in the well were higher than in upstream and downstream samples, indicating potential phosphorus accumulation in groundwater, possibly due to leaching from previous fertilizer applications. Moreover, well and surface water exhibited significantly higher EC values during the dry season, even in the absence of fertilizer application and irrigation, likely due to evapo-concentration of salts (Han et al., 2011).

**Table 1.** Water results on May 29, 2024 (dry season - irrigation and fertilization) from the ACTA BIO Laboratory in Cambodia

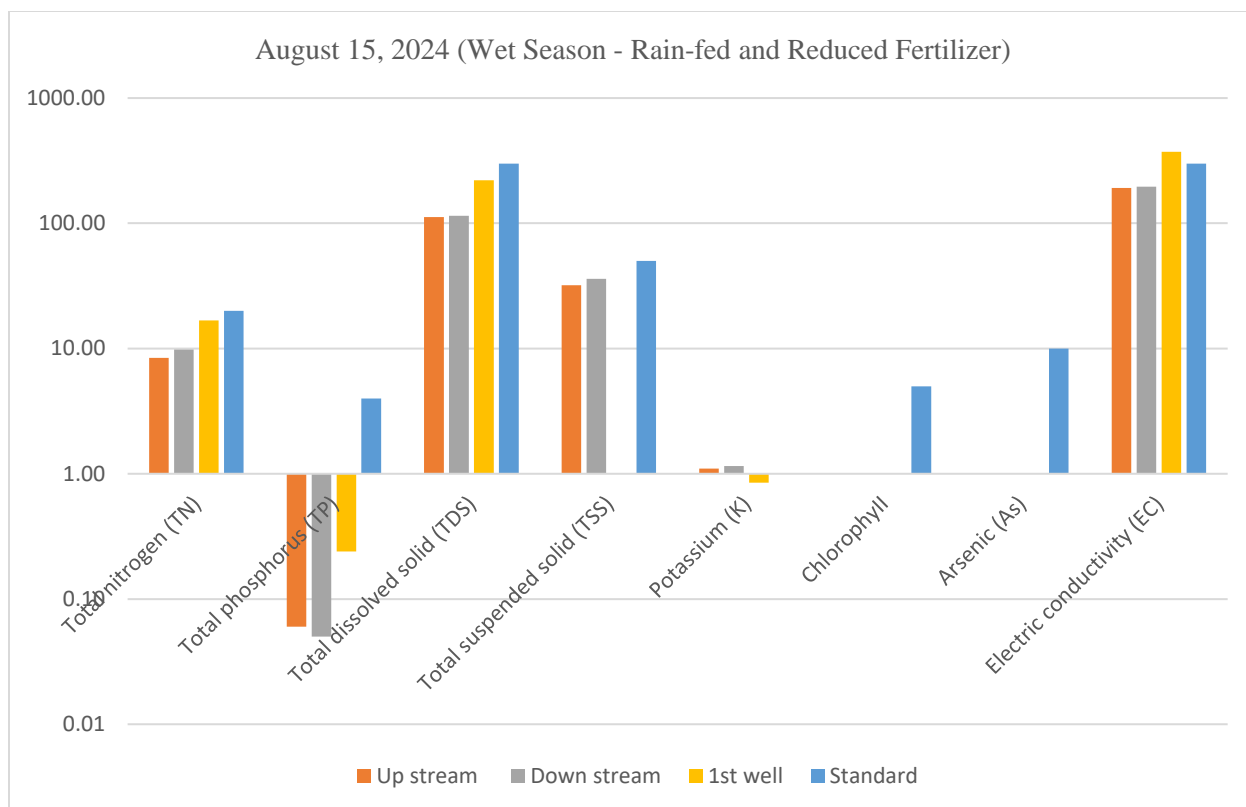
Parameter	Unit	Standard	Up-stream	Down-stream	Well	Testing Methods
pH	-	9.00	7.22	7.12	7.32	AOAC 973.41
Total nitrogen (TN)	Mg/l	20.00	14.00	11.50	12.60	AOAC 960.52
Total phosphorus (TP)	Mg/l	4.00	0.25	0.14	0.16	ISO 15681
Total dissolved solid (TDS)	Mg/l	300.00	209.00	207.00	211.00	AOAC 973.40
Total suspended solid (TSS)	Mg/l	50.00	5.00	8.00	8.50	ISO 11923
Turbidity	NTU	5.00	8.50	10.00	10.00	ISO 7027
Organic matter (OM)	Mg/l		18.00	14.00	12.00	Walkley and Black
Total organic carbon (TOC)	Mg/l	4.60	10.40	8.50	6.90	Walkley and Black
Dissolved oxygen (DO)	Mg/l	6.50	6.80	6.60	5.80	ISO 17289
Potassium (K)	Mg/l	1.00	1.35	1.55	1.15	ISO 9964-3
Chlorophyll	µg/L	5	<5	<5	<5	APHA 10200H



**Figure 7.** Chart of water results on May 29, 2024 (dry season - irrigation and fertilization)

**Table 2.** Water results on August 15, 2024 (wet season - rain-fed and reduced fertilizer) from the ACTA BIO Laboratory in Cambodia

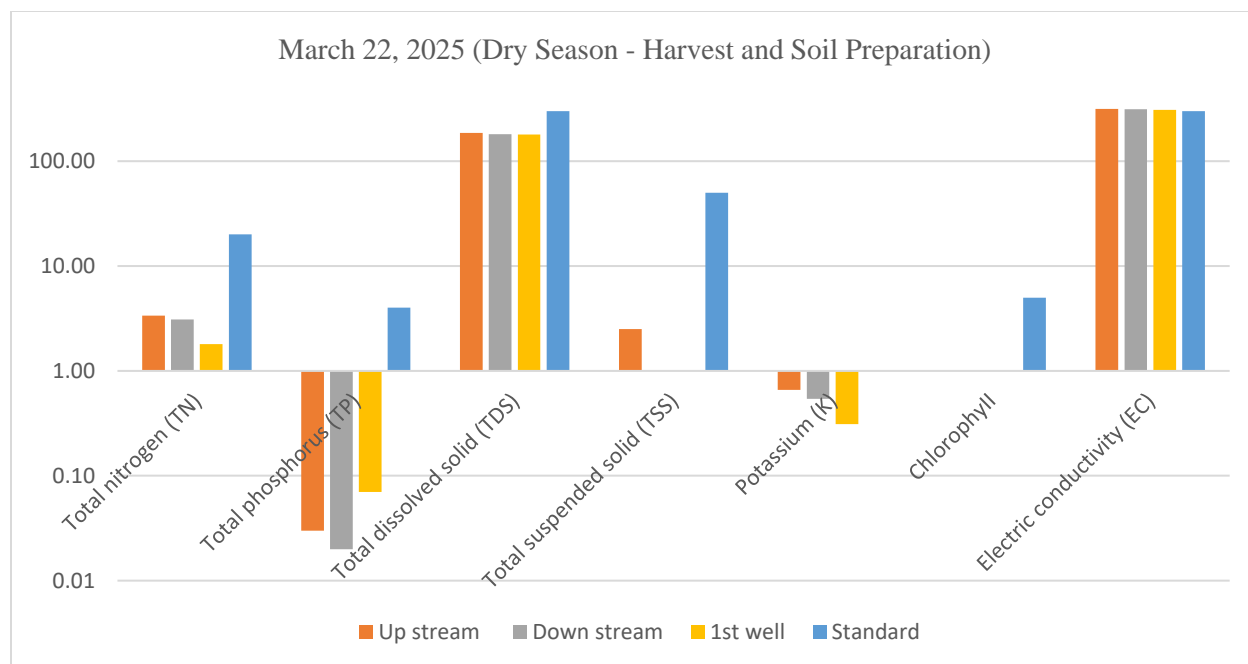
Parameter	Unit	Standard	Up-stream	Down-stream	Well	Testing Methods
Total nitrogen (TN)	Mg/l	20.00	8.40	9.80	16.80	AOAC 960.52
Total phosphorus (TP)	Mg/l	4.00	0.06	0.05	0.24	ISO 15681
Total dissolved solid (TDS)	Mg/l	300.00	112.00	115.00	221.00	AOAC 973.40
Total suspended solid (TSS)	Mg/l	50.00	32.00	36.00	1.00	ISO 11923
Potassium (K)	Mg/l	1.00	1.10	1.15	0.85	ISO 9964-3
ChlorophyllII	µg/l	5	<5	<5	<5	APHA 10200H
Arsenic (As)	µg/l	10	-	-	0.00	ISO 17378
Electric conductivity (EC)	µS/cm	300.00	192.00	196.00	373.00	AOAC 973.40



**Figure 8.** Chart of water results on August 15, 2024 (wet season - rain-fed and reduced fertilizer)

**Table 3.** Water results on March 22, 2025 (dry season - harvest and soil preparation) from the ACTA BIO Laboratory in Cambodia

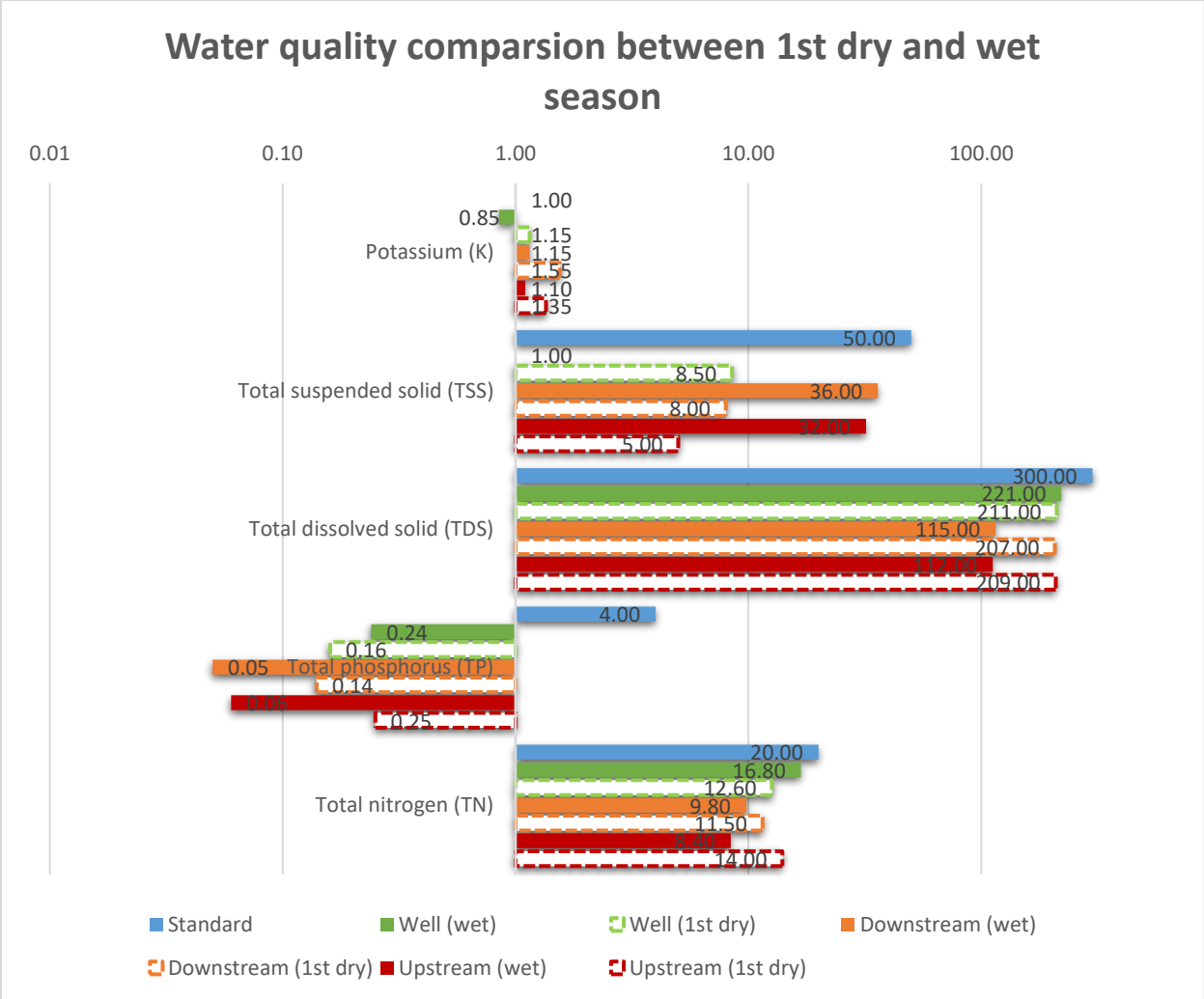
Parameter	Unit	Standard	Up-stream	Down-stream	Well	Testing Methods
Total nitrogen (TN)	Mg/l	20.00	3.36	3.10	1.80	AOAC 960.52
Total phosphorus (TP)	Mg/l	4.00	0.03	0.02	0.07	ISO 15681
Total dissolved solid (TDS)	Mg/l	300.00	186	181	179	AOAC 973.40
Total suspended solid (TSS)	Mg/l	50.00	2.50	1.00	<1.00	ISO 11923
Potassium (K)	Mg/l	1.00	0.66	0.54	0.31	ISO 9964-3
ChlorophyllII	µg/l	5	<5	<5	<5	APHA 10200H
Electric conductivity (EC)	µS/cm	300.00	316	313	308	AOAC 973.40



**Figure 9.** Chart of water results on March 22, 2025 (dry season - harvest and soil preparation)

***May 29, 2024 (Dry Season - Irrigation and Fertilization) vs. August 15, 2024 (Wet Season - Rain-fed Agriculture)***

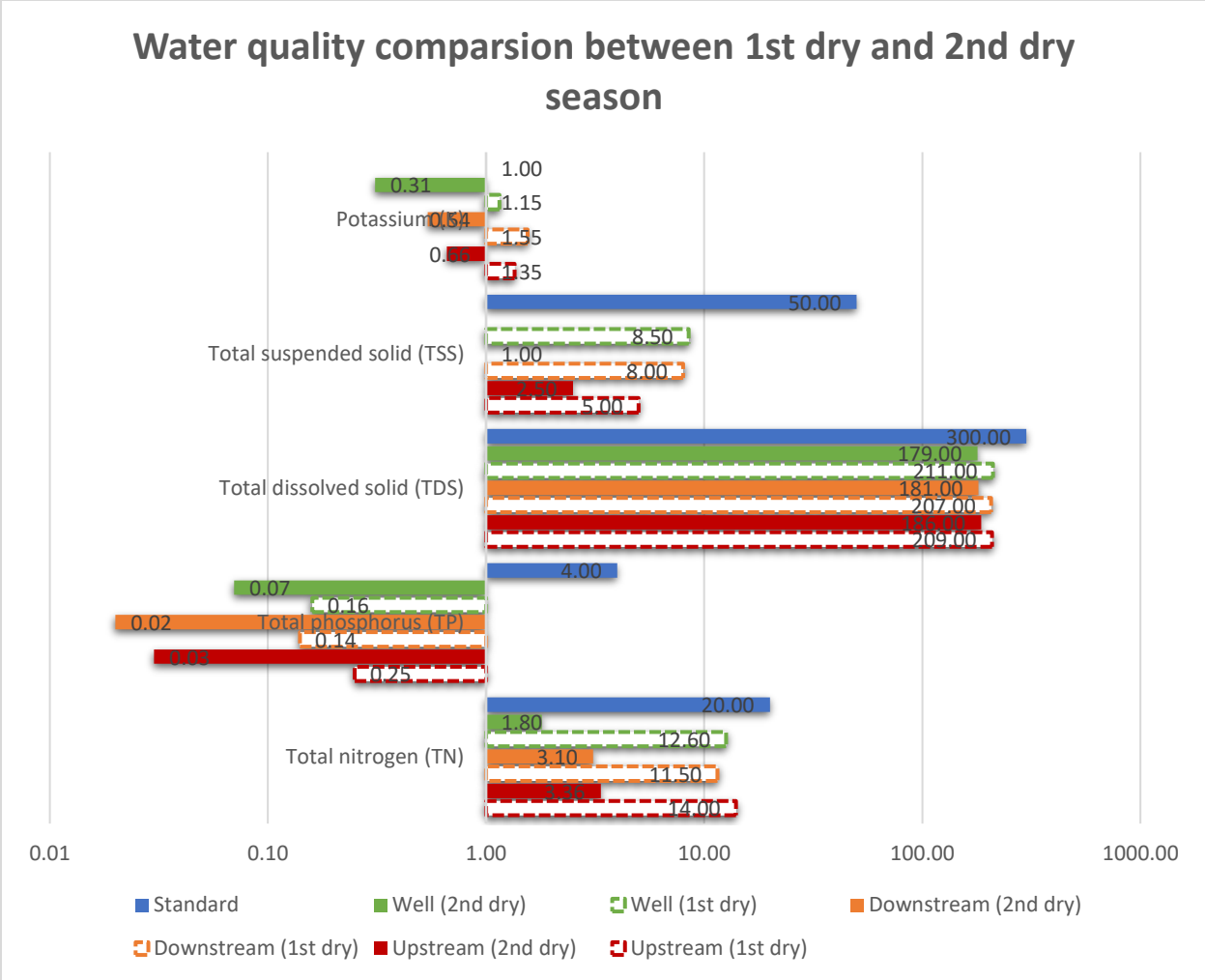
Water quality analysis revealed that TN, TP, K, and TDS levels in upstream and downstream locations were higher in the dry season (irrigation and fertilization) compared to the wet season (rain-fed and reduced fertilizer) (Figure 10). Evidently, reduced fertilizer application and the rainfall during the wet season helped dilute nutrient concentrations and reduce surface water contamination. The fact that groundwater, which is closest to the farm, showed lower TN, TP, and TDS levels in the dry season, even though more agricultural practices were conducted, indicates that agricultural runoff alone could not be the primary contributor to surface water contamination. Instead, external pollution sources could be amplifying nutrient concentrations in surface water, leading to higher TN, TP, and TDS levels in the dry season. However, groundwater samples exhibited higher TN, TP, and TDS levels in the wet season, possibly due to increased leaching from heavy rainfall. Additionally, TSS was higher in the wet season, reflecting increased soil erosion and sediment transport due to runoff (Chang et al., 2021).



**Figure 10.** Chart of water results comparison between the dry season (irrigation and fertilization) and the wet season (rain-fed and reduced fertilizer)

***May 29, 2024 (Dry Season - Irrigation and Fertilization vs. March 22, 2025 (Dry Season - Harvest and Soil Preparation)***

The comparison between the first (irrigation and fertilization) and the second (harvest and soil preparation) dry season showed a significant reduction in TN, TP, TDS, TSS, and K levels in the latter period (Figure 11). This decline suggested that post-harvest conditions and soil preparation practices contributed to reduced nutrient and sediment loads in both surface water and groundwater. Reduced fertilization and irrigation activities during this phase may have minimized runoff and leaching of contaminants.



**Figure 11.** Chart of water results comparison between the dry season (irrigation and fertilization) and the dry season (harvest and soil preparation)

**2. Focus Group Interview**

The focus group interview analysis revealed key themes related to irrigation practices, fertilizer application, manure management, and farmer perceptions of water quality (Tables 4 & 5). A total of five farmers participated, contributing 56 coded responses across various themes. Themes were analyzed to explore how agricultural practices, such as irrigation and fertilizer management, directly or indirectly impact water quality (Table 6).

***Irrigation Practices and Seasonal Variation***

Farmers described distinct seasonal irrigation patterns, with dry season irrigation occurring up to three times per day using spray hoses and tube irrigation, while wet season irrigation was limited to once or twice daily due to natural rainfall. One farmer emphasized:

*"During the dry season, we must irrigate frequently, but this causes more soil to wash away into the water."*

### ***Fertilizer Use and Perceived Benefits***

All participating farmers relied heavily on chemical fertilizers such as UREA and DAP, often exceeding recommended application rates to boost crop yields. One farmer noted:

*"We know fertilizers are good for crops, but too much is bad for the soil and water. We have no choice if we want better yields."*

### ***Manure Management and Usage Decline***

Three farmers mentioned a decline in manure use over the past decade, citing logistical challenges and limited access to livestock farms. As one participant explained:

*"In the past, we used manure because it made the soil better. But now, it's hard to get, so we rely more on chemical fertilizers."*

### ***Perceptions of Water Quality and Responsibility***

When asked about changes in water quality, all five farmers acknowledged observable differences, particularly increased turbidity during the dry season. One stated:

*"The water looks dirtier after heavy fertilizer use, but it could also be from other farms or the rain-washing things in."*

**Table 4.** Farmers’ perspectives on agricultural practices and water quality in relation to seasonal farming practices

<b>Theme</b>	<b>Key Findings</b>	<b>Number of Farmers Mentioning</b>	<b>Representative Quote</b>
<b>Irrigation Practices and Seasonal Variation</b>	Dry season irrigation up to <b>3 times per day</b> using spray hoses; wet season limited to <b>1–2 times daily</b> due to rainfall. The main concern was <b>soil erosion and nutrient runoff</b> from excessive irrigation.	4 out of 5	<i>"During the dry season, we must irrigate frequently, but this causes more soil to wash away into the water."</i>
<b>Fertilizer Use and Perceived Benefits</b>	Heavy reliance on <b>chemical fertilizers (UREA, DAP)</b> , often exceeding recommended application rates. Organic fertilizer adoption was low due to cost constraints.	5 out of 5	<i>"We know fertilizers are good for crops, but too much is bad for the soil and water. We have no choice if we want better yields."</i>

<b>Manure Management and Usage Decline</b>	<b>Declining use of manure</b> due to logistical challenges and limited access to livestock farms. Some farmers still use manure as a soil amendment.	3 out of 5	<i>"In the past, we used manure because it made the soil better. But now, it's hard to get, so we rely more on chemical fertilizers."</i>
<b>Perceptions of Water Quality and Responsibility</b>	All farmers observed <b>water quality changes</b> , particularly <b>increased turbidity during the dry season</b> . However, only 2 linked it directly to their farming practices.	5 out of 5	<i>"The water looks dirtier after heavy fertilizer use, but it could also be from other farms or the rain-washing things in."</i>

**Table 5.** Annual crop cycle practices of Teuk Vil farmers

Practices (yearly rotation)	Activity	Method/Type	Period
<b>Soil Preparation</b>	Plow	Animal; Machine	1-1.5 months
	Fertilizer	Compost; Manure (12t/ha); DAP (250kg/ha or 2kg/a); Herbicides; Soybean seed	40 days
	Irrigation	Sprinkler; Hose or Tube (morning/noon/evening) (dry); (morning/evening) (wet)	Daily
<b>Plantation &amp; Care</b>	Seeding	Corn; Cabbage; Garlic; Herb; Lettuce; Green onion	
	Fertilizer	UREA (250kg/a or 2kg/a) (dry) (150kg/a) (wet)	3 times for 1-1.5 months (dry), 2 times (wet)

	Irrigation	Sprinkler (morning/noon/evening) (dry); (morning/evening) (wet)	Daily
Harvest		Human	1-2 months

**Table 6.** Impacts of agricultural practices on water quality: insights from farmer perceptions

Research Question	Theme	Qualitative Insights	Quantitative Evidence	Implications
What agricultural practices significantly influence water quality?	<b>Nutrient Pollution from Farming Practices</b>	Overuse of chemical fertilizers leads to nutrient runoff. Farmers recognize this but cite cost barriers to alternatives.	Elevated nitrate levels in downstream water samples compared to upstream.	Indicates a need for better access to sustainable fertilizers and training on optimized application methods.
	<b>Irrigation Practices</b>	Irrigation frequency varies by season, with more intensive use during dry periods, leading to soil erosion.	Increased sedimentation levels during the dry season compared to the wet season.	Suggests improved irrigation scheduling and erosion control strategies.
	<b>Barriers to Sustainable Practices</b>	Farmers face challenges such as limited access to organic inputs and lack of incentives for sustainable farming.	Lower adoption rates of organic fertilizers in surveyed farms.	Highlights a need for policy interventions to improve access to sustainable inputs and provide financial incentives.
What are farmers' perceptions of water quality and its management?	<b>Awareness of Environmental Impacts</b>	Mixed awareness: some farmers understand runoff effects, while others lack information on how practices affect water.	Qualitative feedback aligns with varying water quality perceptions in focus groups.	Demonstrates the importance of targeted awareness campaigns tailored to local farming communities.
	<b>Adaptation to Seasonal Variability</b>	Farmers adapt irrigation and fertilization practices based on seasonal water availability and crop needs.	Seasonal variation in water quality metrics, such as higher nutrient runoff during rainy seasons.	Highlights opportunities to align practices with environmental conservation goals through seasonal best practices.

## Discussion

### 1. *Water Quality*

Across all three sampling rounds, TN, TP, TDS, TSS, and chlorophyll levels remained within acceptable water quality standards, indicating no immediate concerns regarding these parameters. However, K levels surpassed the water quality standard in Cambodia during the plantation process in the dry season when farmers heavily applied fertilizers. This finding aligned with Mair et al. (2013), who highlighted that fertilizer residues can contribute to long-term contamination in water sources. Therefore, to answer the first question of the project objective, one of the agricultural practices associated with declining water quality was the use of fertilizer. In addition to agricultural pollution, elevated K levels could also stem from other sources, such as domestic wastewater and industrial discharge. It aligns with previous studies (Elias et al., 2013), which have documented that while agriculture is a major contributor to nutrient runoff, additional sources, such as urban development and natural geochemical processes, also play a role in water quality degradation. To the second key research question, elevated turbidity levels observed during the plantation in the dry season suggested that irrigation-induced soil erosion contributed to sedimentation in nearby streams, especially when irrigation was actively applied. Moreover, upstream turbidity exceeded acceptable standards even before reaching downstream areas, indicating that urban development may contribute more significantly to sediment than irrigation runoff during peak agricultural activity. Additionally, EC remained high in both well and surface water in the dry season, indicating natural processes like evaporation and past nutrient loading can significantly influence EC. These results highlighted the complex interactions between land use, water management, and hydrological conditions (De Mello et al., 2020). Importantly, high K levels may affect ecosystems and human health if used for drinking without filtration. Elevated turbidity can degrade aquatic habitats and reduce environmental aesthetics. Increased EC relates to salinity, which can lower crop productivity.

### 2. *Focus Group Interview*

The findings aligned with existing literature emphasizing the impact of agricultural practices on water quality. Similar to the observations by Carr (2011) in Jordan and to address the third key research question, Cambodian farmers also recognized the benefits of fertilizers for crop productivity while acknowledging their detrimental effects on water quality. However, the Cambodian context involves a strong seasonal dimension, with practices varying significantly between wet and dry seasons due to the region's monsoonal climate. The identified overuse of chemical fertilizers mirrored findings from (Shrestha, 2020), where farmers in Cambodia and Myanmar faced similar challenges.

### 3. *Overall Interpretation*

The combined water quality analysis with farmer interviews in the Socio-Hydrology Framework confirmed that sediment and nutrient runoff from farms and urban development could contribute to water quality degradation. It also revealed that farmers' perceptions are shaped by both awareness of environmental consequences and limited resources to change practices.

## Conclusion

In conclusion, this study provided valuable baseline data on water quality trends and regional agricultural practices, serving as a foundation for future policy recommendations. The findings emphasized the urgent need for targeted interventions that balance agricultural productivity with environmental sustainability. Addressing these challenges required a collaborative approach involving farmers, policymakers, researchers, and local stakeholders. Moving forward, the implementation of best practices such as optimized fertilizer application, erosion control strategies, and integrated water management will be crucial in ensuring the long-term sustainability of both agricultural productivity and water resources in Cambodia. However, future research should further investigate non-agricultural pollution sources, particularly domestic and industrial contributions, to develop a more comprehensive watershed management strategy.

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## Appendices

### Appendix A: Questionnaire Structure of Interview with Farmers

#### Interview Questions

##### Section 1: Personal Information

1. What is your name, age, sex, role (Owner, business, or worker), phone number, family and address?
2. How many years have you been involved in agricultural practices?
3. What is the size of your farm in acres?

##### Section 2: Agricultural Practices

###### Current Agricultural Practice

4. Which crops do you primarily cultivate and rotate on your farm?
5. Could you describe your current irrigation practices? (1. method: surface, drip, sprinkler, 2. frequency)
6. What types of fertilizers do you use, and how do you manage their application? (type, application rate, timing of application, placement, and management practice)
7. How do you manage manure on your farm? (cover crop, storage, treatment technology, nutrient management, application timing and method)

###### Agricultural Practice for the last 5 years

8. Which crops do you primarily cultivate and rotate on your farm?
9. Could you describe your current irrigation practices? (1. method: surface, drip, sprinkler, 2. frequency)
10. What types of fertilizers do you use, and how do you manage their application? (type, application rate, timing of application, placement, and management practice)
11. How do you manage manure on your farm? (cover crop, storage, treatment technology, nutrient management, application timing and method)

##### Section 3: Water Quality and Sustainability

12. Have you observed any changes in water quality near your farm over the past five years?
13. In your opinion, what are the main factors influencing water quality in your area?
14. How do you think agricultural practices impact water quality in nearby water sources?
15. What measures do you take to minimize the environmental impact of your agricultural activities on water quality?
16. Are you familiar with any water quality testing initiatives or programs in your area?
17. Do you believe there is a need for improved water quality management in agriculture? Why or why not?
18. What type of water are you using for domestic and agriculture?
19. Have you ever had health problems (diarrhea, stomach ache, skin itchy...) related to your water usage?

##### Section 4: Perspectives on the Proposal Project

20. What are your thoughts on the proposed project "Enhancing Water Quality and Sustainability in Agriculture in Cambodia"?
21. Do you see any potential challenges or benefits associated with implementing the project?
22. How do you think the findings from this project could benefit farmers and the agricultural community in Cambodia?
23. Would you be interested in participating in the research activities of this project, such as interviews or water quality testing?

Section 5: Additional Comments

24. Is there any additional information, feedback, or suggestions you would like to share regarding water quality and sustainability in agriculture in Cambodia?

Extra Questions

25. Describe farming from the beginning to the harvest of each crop.

**Appendix B: Interview code book**

Name	Description (Memo)
Climate change	Farmers mentioned how difficult it is to get the water from the ground. Since the climate is changing from year to year, they are facing on drought or less water in the water well.
Drought	
Expectation from this project	What farmers expected from this project
Better understanding of crop quality	
Better understanding of soil quality	
Environment protection	
Human health protection	
More attention from the team	
Standard agriculture practices from outside countries	

Name	Description (Memo)
Understanding of water source protection	
Advantages of water quality improvement	
Water quality protection	
Very satisfied with this project	How much they satisfied to help with the project and expected from it.
Farmer's experiences term	How long of farmers' experience in agricultural practices
At least 15 years	
Farm's size	Farm size of each farmer who owns the farm property
At least 5000 m2	
Fertilizer Process	Description of the fertilizer used over the past unit present. It describes what type of fertilizer/how they use/ how much they use/ how long/ and how they use it for each type of crop. Very detailed on each season in each step of practice.
Fertilizer Process in the past	
Use more animal fertilizer (manure)	
Soil quality was better	
Harvest_3rd stage	
1 month	
45 days for cabbage	
45 days for Garlic	

Name	Description (Memo)
45 days for lettuce	
60 days for Basil	
70 days for corn	
Plantation_2nd stage	
Dry season	
1 time a day (2 to 3 rounds)	
Apply in 2 weeks after soil preparation	
Next, apply after 10 days	
Pesticides	
UREA (250 kg per ha)	
Lettuce (100 kg per ha to 150 kg per ha)	
Wet season	
Increase DAP	
Reduce UREA	
UREA (150 kg per ha)	

Name	Description (Memo)
Soil Preparation_1st stage	
2 to 3 rounds per dry season	
Fertilizer type	
DAP (250 kg per ha)	
Manure or Compost (12 tons per ha)	
Only dry season	
Soybean seed	
Plow or burry in the ground	
After 2 weeks before applying fertilizer	
Plow for 45 days	
Impact of agriculture practices	The opinions on how the practice may impact those around us
Crop yields	
Direct impact	
Fertilizer	
Environment and Biodiversity	
Human health	

Name	Description (Memo)
Impossible	
Indirect impact	
Soil quality	
Water quality	
Pond contamination	
Irrigation Process	Description of the irrigation used over the past unit present. It describes what type of irrigation/how they use/ how many times they use it. Very detailed on each season in each step of practice.
Irrigation process in the past	
Dry season (3 times a day)	
Irrigation type	
short hose	
Wet season (1 to 2 times a day)	
Irrigation type	
Spray hose	
Sprinkler	
Method in Dry season	
3 times a day	
Method in Wet season	
2 times a day	
Soil moisture	
Manure Process	Describe the manure process if they are still using it
Animal farms are far from agricultural farm	

Name	Description (Memo)
Observation of water quality	Farmers have observed the water quality of groundwater and surface water by eye these years.
Arsenic of domestic well	
Dirty water (rainy season)	
Unclear	
Participant's gender	The gender of farmers who participated in this interview
Male farmers	
Solution for water contamination	How the farmers think of effective solutions or methods to increase and protect water quality of water sources near their farm
Increase awareness of protection	
Reduce pesticides	
Remain hygiene (after fertilizing)	
Type of crop	The type of crop that farmers are planting over the year in each season
Diversified crop	
Fruit	
Corn (dry season)	
Leafy	
Basil	
Cabbage	
Lettuce	
Root	
Garlic (dry season)	

Name	Description (Memo)
The water source for domestic	Water sources for domestic that the farmers are using
Company water	
Water sources for irrigation	Water sources for irrigation or agriculture practices that the farmers are using
Not using river at all	
Well	

## Appendix C: Interview Guides

### Verbal interview guide

1. Introductions: Name, age, role, and summary of background.
2. Read verbal consent script and obtain and record consent.
3. Express appreciation for participants.
4. Reason for interview: I have invited you because I'm very curious about your perspective as a ranger, the challenges you're facing, and some different work dynamics you experience with your colleagues.
5. Goal of interview: I hope in the end that I will understand better what is going on with your work as a ranger, what you're dealing with, and also how you see possible solutions for the challenges you are facing.
6. Determine duration: Is around 45 minutes alright? Sometimes it will only take half and hour, but sometimes it goes over one hour.
7. I will be taking some notes during this interview, and if it's ok, I will also be recording it, but it's only for me so I can remember what you've said.
8. Do you have any questions?
9. Can we start the interview?

**Talking points:** *These are meant to be flexible questions that stimulate discussion, rather than dictate it. This will allow for emergent understandings to develop and for complex, nuanced viewpoints to be heard by the researcher.*