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Original Article

Influence of Farming Practices within and adjacent to the Riparian Ecosystems on the Water Quality of the Lukuledi River, Lindi-Tanzania

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ABSTRACT

Today, the world is facing a global water crisis, with expanding farming practices driven by population growth and agricultural demand degrading water resources. Farming practices in areas within and adjacent to the riparian ecosystems of the Lukuledi River have increased contaminant release, negatively affecting the aquatic ecosystem of the river. However, there is limited knowledge on the consequences of these practices and their influence on the water quality of the river. This study identified farming practices within and adjacent to the Lukuledi River and assessed their influence on the river's water quality. Four clusters were established along the river continuum. The first cluster (Cluster I) was established upstream in the protected Rondo Nature Forest Reserve, while the other clusters (Clusters II to IV) were located midstream and downstream in the agricultural landscape. Farming practices in clusters II to IV were assessed using household socio-economic data collected through structured questionnaires and direct field observation. In each of the four clusters, water quality parameters, including pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Temperature (T), were measured in situ using a multiparameter analyser (HI-9829). The recorded farming practices were analysed using IBM SPSS Statistics 27, and the results were presented using descriptive statistics. The same software was also used to analyse water quality parameters and the results were presented as descriptive statistics (mean concentration). The identified farming practices include shifting cultivation, mixed cropping, intercropping, monocropping, irrigation farming (basin and canal/furrow), free-range and zero grazing, along with the use of fertilisers and agrochemicals. The mean concentrations of water quality parameters were significantly higher in downstream clusters compared to the upstream cluster. However, pH was below TBS and WHO standards in upstream Cluster I but met the standards in midstream and downstream Clusters. DO was below WHO standards throughout but met TBS standards in downstream Clusters III and IV, while remaining below in upstream and midstream. Temperature met TBS and WHO standards in upstream Cluster I, but exceeded in midstream and downstream clusters. EC and TDS values remained within TBS and WHO limits. There was a positive correlation between the farming practices and water quality. These findings suggest that farming practices within and adjacent to the river alter the water quality and key aquatic ecosystems. Thus, monitoring of agricultural practices is essential to mitigate negative impacts on the Lukuledi River ecosystem and preserve its water quality.

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INTRODUCTION

Rivers are vital freshwater ecosystems that support diverse life forms and serve essential functions for human survival, environmental balance, and economic activities (Miima *et al*., 2011). They play a crucial role in shaping landscapes and providing various ecosystem services, including freshwater supply for domestic, agricultural, and industrial uses, power generation, habitat provision for diverse aquatic and terrestrial life, climate regulation, and recreational spaces (Orozco-González & Ocasio-Torres, 2023). However, rivers are highly susceptible to human activities, with agriculture involving different farming practices serving as a major global driver of their degradation (Mwaijengo, 2020). Farming practices include all methods and techniques used by farmers to grow crops and raise livestock.

These practices include preparing the land, planting and growing, protecting, harvesting, and managing crops and animals. Farming practices can vary depending on factors like climate, soil type, available technology, culture, and economic conditions (Amayo *et al*., 2021). The rapid expansion of farming practices, driven by population growth and increasing demand for agricultural products, is exerting significant pressure on the water resources of rivers. Farming practices within riparian zones can have serious impacts on water quality, riverbank stability, aquatic biodiversity, and ecosystem health (Ontumbi *et al.,* 2015; Monteiro *et al*., 2021). Farming practices contribute to increased salinity, nutrient levels, and sedimentation in water bodies, alter hydrological regimes, and degrade in-stream habitats and riparian vegetation (Akamagwuna, 2021).

Additionally, farming practices have disrupted the natural erosion process, affecting sediment deposition in rivers and altering water quality, which in turn impacts aquatic organisms (Ayivor & Gordon, 2012). The misuse of Fertilisers, pesticides, and unsustainable practices like bush burning can lead to eutrophication, an excess of nutrients in surface and groundwater that harms aquatic life and human communities (Ayivor & Gordon, 2012). This issue is especially severe in developing countries, where agriculture is a primary economic activity, yet many farmers lack the resources and technology to implement sustainable practices (Zahoor & Mushtaq, 2023). Farming practices have far-reaching consequences for the environment, human health, biodiversity, and food security. However, their impact varies across regions due to differences in population

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density, land use, and farming techniques (Wyer *et al*., 2022).

In the U.S. and Australia, excessive Fertiliser and pesticide use are major contributors to groundwater pollution (Akhtar *et al.*, 2022). In contrast, in India and other developing nations, traditional farming practices, inadequate infrastructure and low farmer literacy are primary causes of agricultural water pollution. Contaminants such as heavy metals, salts and pathogens from agricultural operations degrade water bodies, rendering land barren and harming aquatic life (Akhtar *et al.*, 2022). In East Africa, Farming practices have led to widespread deforestation and is a primary stressor on rivers and streams. Crop cultivation has been linked to increased water temperature, conductivity, turbidity, and sedimentation in water bodies (Kasangaki *et al*., 2008). Farming near streams and rivers directly impacts stream habitats and aquatic life (Raburu *et al*., 2009).

In Tanzania, land degradation due to deforestation, overgrazing, wildfires, and crop cultivation has been a growing concern (Muthui & Muthui, 2015). The country's agricultural sector has experienced significant growth due to population increases and rising demand for both subsistence and commercial farming (Wineman *et al*., 2020). Unregulated irrigation and livestock grazing along riparian zones contribute to excessive siltation and sedimentation, deteriorating water quality (Koskey *et al.,* 2021). The expansion of agriculture, coupled with population growth, has led to the removal of riparian vegetation, both directly through land clearance and indirectly through water contamination (Rajabu *et al.,* 2024).

In Lindi and Mtwara regions, the high profitability of sesame compared to other crops like maize, rice, sorghum, and millet has driven more farmers to clear land rather than adopt modern inputs to increase yields, leading to deforestation and land degradation (Mashindano & Kihenzile, 2013; Lokina *et al.,* 2020). Miya *et al*. (2012) have reported growing human population, economic growth, livestock farming, timber trade and charcoal production as the main drivers of deforestation in Kilwa District. This is also happening in Lindi district, especially along the Lukuledi River in search of water and fertile alluvial soils for subsistence and commercial farming, which contaminate water and cause vegetation loss in the riverine ecosystems, negatively affecting the water quality of the river. However, there is limited knowledge of the consequences of these farming practices on the river's water quality. The objectives of this study were to (1) identify and describe farming practices along the longitudinal section of the Lukuledi River catchment and (2) assess the influence of the farming practices on the water quality of the river. Findings from this study will provide baseline information and recommendations to protect the Lukuledi River and potentially the best approaches for sustainable management of the river ecosystem.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted along the Lukuledi River catchment in Lindi district. The river is located between the boundaries of Lindi and Mtwara regions, where some of its tributaries originate from the Rondo escarpment, passing through the Rondo Nature Forest Reserve. The river catchment lies between 10^0 4' 600'' south of the equator and 39^0 42'0'' east of the equator, running eastwards in the Lindi region, emptying its water in the Indian Ocean near Lindi town (Figure 1). The area has an average annual temperature of 27^0C during the hot season and 24^0C during the cold season. It receives an annual rainfall ranging from 800mm to 1000mm, with one rainy season which starts and ends in November and May, respectively. The area experiences a dry period at the end of January and February. The soils are from well-drained sandy loams, dark cracking clays and sandy clays formed from lacustrine and riverine alluvium in the valley and flood plains. The area is characterised by sparse vegetation covered with natural vegetation consisting of scattered trees, shrubs and thickets. Some of the common plant species found in the vegetation of this area are *Ceiba pentandra, Trichilia emetica, Dalbergia melanoxylon, Commiphora africana, Militia excelsa, Hymenea*

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verrucosa, Launea cornuta and *Ageratum conyzoides* (Clarke, 2001; Temu, 2013).

Socio-economic Activities

The main economic activity of the area is farming, including crop cultivation and animal husbandry by about 80% of the entire population (Lokina *et al.*, 2020). Farming tools are mostly hand hoes, slashers, axes, and machetes for farm preparation. The main crops produced are maize, rice, cowpeas, pigeon peas, sorghum, cassava, banana and sweet potatoes, for subsistence or food. Commercial crops include coconuts, sesame and cashew nuts. The livestock component includes cattle, goats, sheep, pigs and poultry. Fishing, timber harvesting and charcoal are also among income-generating activities (Temu, 2013).

Sampling Design

Four clusters were located along the longitudinal continuum of the river from which sampling points were located (Table 1 & Figure 1).

Table 1: Cluster's Location at the Lukuledi River Catchment

Cluster Location	Farming Activities	Elevation (M.A.S.L)	Distance Between Clusters	Vegetation Description
Cluster 1 (Upstream)	Human activities are limited and considered a pristine site	458 – 393	10km between clusters 1 and 2	Relatively intact riparian vegetation, characterised by dense natural forests with multiple canopy layers, including indigenous tree species and diverse understory vegetation.
Cluster 2 (Midstream)	Crop cultivation and livestock grazing are occurring and considered among the non-point source areas generating pollutants and thus, pollution sources	258 – 241	5km between clusters 2 and 3	A mixed vegetation pattern where natural vegetation interfaced with agricultural lands, showing patches of secondary forest growth interspersed with crop fields and scattered remnant native trees.
Cluster 3 (Downstream)	Crop cultivation, livestock grazing, and irrigation farming and considered pollutant receivers	215 – 174	5km between clusters 3 and 4	Vegetation patterns are predominantly characterised by agricultural crops, scattered native trees, and herbaceous plants.
Cluster 4 (Downstream)	Crop cultivation, livestock grazing, and irrigation farming and considered pollutant receivers.	160 – 141		Vegetation patterns, predominantly characterised by agricultural crops, scattered remnant native trees, shrubs, herbaceous plants and grasses.

In each of the four clusters, 12 sampling points were established along the river continuum, with an 85m distance between consecutive points. At each sampling point, physicochemical parameters of water quality were measured, especially pH, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), and temperature.

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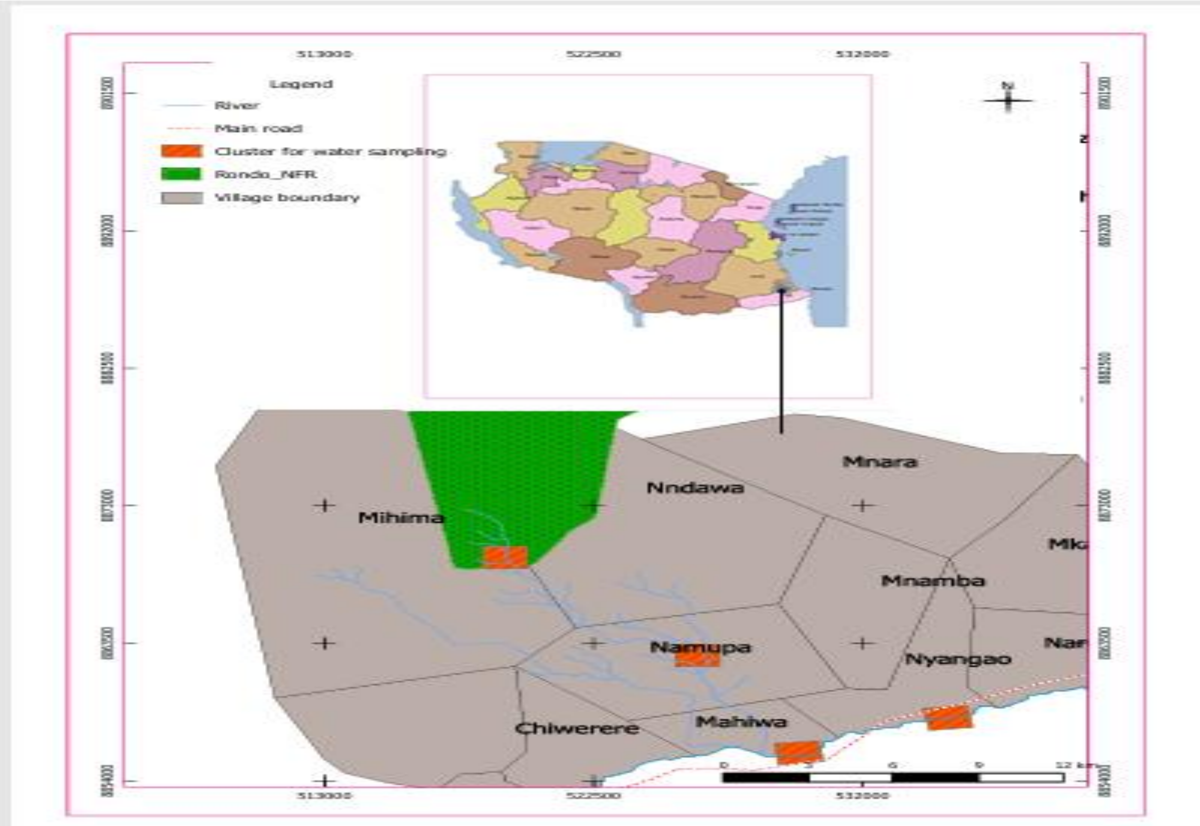
Figure 1: Location of the Study Area



Source: *Drawn by using GIS, Author, 2025*

Data Collection

Identification and description of farming practises within and adjacent to the Lukuledi riparian ecosystems

Sampling was done from clusters 2 to 4 in the agricultural landscape adjacent to the Lukuledi River. To avoid bias during data collection, a random sampling technique was used to recruit household respondents from the list provided by the village leaders and extension officers (livestock and agriculture). In each cluster, farm households were interviewed using a structured questionnaire consisting of open and closed ended questions disseminated to only one respondent, who was the head (father, mother or any family member above 18 years in the absence of a household head) and guided by the researcher to identify and describe the farming practices of the study area. The number of households chosen varied between clusters due to differences in population. The study area has a population of 1905 households per the 2022 population and housing census (URT, 2022). For the determination of a sample size for each cluster, the formula below, developed by Yamane (1967), was used.

$$n = \frac{N}{1+Ne^2}$$

Where by

n = sample size, N = Total population size, e = Margin of error or allowable error (10%).

Based on the population and the above formula, the sample size was 95 as per the computation below:

$$n = \frac{1905}{1+1905(0.1)^2}$$

n = 95

The created sample size from the Yamane 1967 formula in this study was 95, although 114 households were sampled instead of 95 to capture more diversity in farming practices across the study area, account for non-responses and improve data

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reliability. The households sampled were chosen randomly from the population to minimise sampling error and bias, as it produces a representative sample from the target population by ensuring that every individual in the population has the same chance of being included in the sample, preventing systematic exclusion of certain groups (Singh & Masuku, 2014). The sample size for each cluster is shown in Table 2 below. Apart from household interviews, direct field observation was made for ground truthing. Table 3 presents the information collected for each household.

Table 2: Sampling Frame and Sample Size (Kothari 2004)

S/N	Cluster	Sampling Frame	Proportion	Sample Size
1	Cluster 2	625	625/1905*114	37
2	Cluster 3	760	760/1905*114	46
3	Cluster 4	520	520/1905*114	31
		1905		114

Table 3: Household Information Collected during the Survey

Socio-demographic variables	Gender, age, education, household income and household size
Land preparation techniques	Clear and burn the bush, ploughing, tillage
Crop planting methods or techniques	Cropping pattern (monocropping, intercropping, mixed cropping, relay cropping, crop rotation, shifting cultivation) and crop grown in each method/technique
Water management techniques	Contour terracing, mulching, planting cover crops and irrigation methods
Soil fertility management	Use of organic and inorganic Fertilisers
Pest and disease management	Mechanical control, biological control, chemical control and integrated pest and disease management
Livestock farming practices	Rotation grazing, free range grazing and zero grazing

Physicochemical Parameters of Water Quality

The physicochemical parameters of water quality assessed during the study included pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Temperature (T). The parameters were recorded in situ using a portable multiparameter water quality analyser HANNA HI-9828. The selection of these parameters for water quality assessment was due to their ubiquity and ease of measurement in the field, but also, they are the main parameters that define water quality in aquatic ecosystems related to the survival of living aquatic organisms.

Data Analysis

Identification and Description of Farming Practises within and adjacent to the Lukuledi riparian ecosystems

Farming practices adjacent to the Lukuledi River were assessed using household socio-economic data collected through structured questionnaires. The survey was conducted in clusters 2 to 4 downstream in the agricultural landscape and included demographic information such as the gender and age of the household head, household size, household income, and level of education. The farming practices adopted by farming households included shifting cultivation, intercropping, monocropping, crop rotation, mixed cropping, irrigation farming (both basin and furrow), Fertiliser application (organic and inorganic), pest and disease control (mechanical and chemical), and grazing systems (free-range and zero grazing). Data were analysed using a Microsoft Excel Spreadsheet. The Shapiro-Wilk test was used to assess data normality. To determine statistical differences in demographic characteristics and farming practices across the clusters, a Chi-square test was conducted at a 5% significance level. For statistically significant variables, Dunn's post hoc test with Bonferroni correction was applied to identify specific farming practices that varied significantly among the clusters (Table 5). All data analyses were performed using IBM SPSS

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Statistics 27, and the results were presented using descriptive statistics and tables.

Influence of farming practises within and adjacent to the Lukuledi riparian ecosystems on the water quality

In assessing the water quality of the river, physicochemical parameter data were analysed for their mean concentration using the Statistical Package for Social Sciences (IBM SPSS) version 27. The Shapiro-Wilk test was used to reveal the normality of the distribution of the data. The Kruskal-Wallis test at a 5% significance level was used to examine the mean difference of physicochemical water quality parameters between clusters, indicating spatial variation in water quality along the river. These values were then compared with the established standards for drinking water (TBS, 2008) and the internationally established guidelines for drinking water (WHO, 2008). This comparative approach warrants a comprehensive evaluation of water quality by checking whether the values of measured parameters are within both local and internationally set standards. This is crucial for safeguarding public health and effective management of water resources. The standards for each selected water quality parameter in the Lukuledi River were used as guidance for improvement, as they highlight areas where water quality improvements are needed.

Correlation between Farming Practices and Water Quality

To assess the influence of farming practices on the water quality of the river, the percentage of each farming practice in each cluster and the corresponding mean concentration of each physicochemical parameter of water quality at each sampling point were used in the analysis to examine the correlation between farming practices and water quality of the river. Data were tested for normality using the Shapiro-Wilk test, and the result revealed normal distribution. The Pearson correlation analysis using SPSS software was an appropriate choice for such an analysis to determine the correlation between the variables. The farming practices adjacent to the river were considered to be independent variables, and the physicochemical parameters of water as dependent variables. The Pearson correlation produces values between -1 and +1, where the negative values indicate an inverse relationship and the positive values indicate a direct relationship. Results with p-value ≤ 0.05 were considered statistically significant **(Appendix 1).**

RESULTS

Demographic characteristics of farm households within and adjacent to the Lukuledi riparian ecosystems

Most of the farm households were male, 75% and 25% were female-headed. The majority of the households were between 36 and 60 years old, with 67% male and 64% female-headed families. There was no statistically significant difference in age between male-headed and female-headed households ($p = 0.83$). Most of the male-headed households were married, 77% and 50% of the female-headed households were single. There was a statistically significant difference in marital status between male-headed and female-headed households ($p = 0.000$). This means that most of the male-headed households were married, while those headed by females were single. Additionally, most of the households attained primary education, where 51% were males and 68 were females. However, there was no statistically significant difference in educational level between male-headed and female-headed households ($p = 0.30$). The majority of the households had a size between 4 – 6 members for both male-headed and female-headed households. However, there was a statistically significant difference in household size between male-headed and female-headed households ($p = 0.02$). Lastly, most of the households had incomes between 1,000,000 TZS and 3,000,000 TZS, with 71% male-headed and 61% female-headed. However, there was no statistically significant difference in income between male-headed and female-headed households ($p = 0.15$) (Table 4).

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Table 1: Demographic characteristics of farm households within and adjacent to the Lukuledi riparian ecosystems

Variable	Categories	Gender of the farm household			
		Male	**Female**	Chi-square	P-value
Age	18-35	17(20)	7(25)	0.4	0.83
	36-60	58(67)	18(64)		
	Above 60	11(13)	3(11)		
	Total	**86 (75)**	**28(25)**		
Marital	Divorce	3(4)	2(7)	27.1	0.00
	Married	66(77)	9(32)		
	Single	7(8)	14(50)		
	Widowed	10(12)	3(11)		
	Total	**86(75)**	**28(25)**		
Education level	No formal education	13(15)	3(11)	3.7	0.30
	Primary education	44(51)	19(68)		
	Professional training	13(15)	1(4)		
	Secondary education	16(19)	5(18)		
	Total	**86(75)**	**28(25)**		
Household size	Between 1 and 3	37(43)	6(21)	7.6	0.02
	Between 4 and 6	39(45)	21(75)		
	Above 6	10(12)	1(4)		
	Total	**86(75)**	**28(25)**		
Annual household income	Less than 1,000,000	2(2)	3(11)	3.7	0.15
	Between 1,000,000 and 3,000,000	61(71)	17(61)		
	Above 3,000,000	23(28)	8(29)		
	Total	**86(75)**	**28(25)**		

Note: *Numbers in parentheses are in percentage*

Identification and Description of Farming Practices

Farming practises within and adjacent to the Lukuledi riparian ecosystems

Smallholder farmers living within the Lukuledi River catchment had adopted various farming practices for crop cultivation and livestock rearing. Most households in downstream Cluster IV (55%) predominantly practise shifting cultivation compared to upper midstream Cluster II (27%). Chi-square test showed a statistically significant difference in shifting cultivation between the clusters (p = 0.031). Further, Dunn's post hoc test with Bonferroni correction showed a significant difference between midstream Cluster II and downstream Cluster III (p = 0.007), midstream Cluster II and downstream Cluster IV (p = 0.007). However, no significant difference was observed between downstream Clusters III and IV (p = 0.273). Most smallholder farmers in downstream Cluster III (57%) practise intercropping than in upper midstream Cluster II (24%). Chi-square test showed a statistically significant difference in intercropping between the clusters (p = 0.009). Further, Dunn's post hoc test with Bonferroni correction showed a significant difference between midstream Cluster II and downstream Cluster III (p = 0.001), midstream Cluster II and downstream Cluster IV (p = 0.007). However, no significant difference was observed between downstream Clusters III and Cluster IV (p = 0.224).

Mixed cropping is primarily adopted by most farmers in midstream Cluster II (78%), rather than in downstream Cluster III (70%). Chi-square test showed no statistically significant difference in mixed cropping between the clusters (p = 0.664). Monocropping is most prevalent in midstream

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Cluster II (68%) but is less common in downstream Cluster IV (55%). Chi-square test showed no statistically significant difference in monocropping between the clusters (p = 0.521). Fertiliser use also varied among the clusters. Households in downstream Cluster III rely more on inorganic fertilisers for soil fertility (57%) than those in midstream Cluster II (54%) and downstream Cluster IV (48%). Chi-square test showed no statistically significant difference in the use of inorganic fertilisers between the clusters (p = 0.781). Conversely, smallholder farmers in downstream Cluster IV (68%) widely apply organic fertilisers for soil fertility management compared to midstream Cluster II and downstream Cluster III (both at 46%). Chi-square test showed no statistically significant difference in the use of organic fertilisers between the clusters (p = 0.115).

Agrochemicals for pest and disease control are used more frequently in midstream Cluster II and downstream Cluster III (81%) compared to downstream Cluster IV (72%). Chi-square test showed no statistically significant difference in the use of agrochemicals for pest and disease control between the clusters (p = 0.609). Additionally, mechanical pest control methods are more commonly practised in downstream Cluster III (57%) but are less practised in midstream Cluster II (54%) and downstream Cluster IV (48%). Chi-square test showed no statistically significant difference in the use of mechanical pest and disease control between the clusters (p = 0.749). Irrigation farming primarily utilises surface irrigation methods, including basin and furrow/canal systems. Basin irrigation is widely practised in midstream Cluster II (89%) and downstream Cluster IV (87%) but is less common in downstream Cluster III (74%). Chi-square test showed no statistically significant difference in the practise of basin irrigation method between the clusters (p = 0.139). While furrow/canal irrigation is common in midstream Cluster II (76%) and downstream Cluster III (72%), and less common in downstream Cluster IV (61%). Chi-square test showed no statistically significant difference in shifting cultivation between the clusters (p = 0.415).

Livestock farming is predominantly conducted through a free-range grazing system across all clusters, midstream, downstream clusters III and IV (16%, 20% and 48%). Chi-square test showed statistically significant difference in free range grazing system practise between the clusters (p = 0.004). Further, Dunn’s post hoc test with Bonferroni correction showed a significant difference between Cluster II and Cluster IV (p = 0.011), Cluster III and Cluster IV (p = 0.004). However, no significant difference was observed between Cluster II and Cluster III (p = 0.147). There was minimal adoption of zero-grazing methods (8%, 7% and 6%). Chi-square test showed no statistically significant differences in zero grazing practise between the clusters (p = 0.951) (Table 5).

Table 2: Percent of farmers practising different farming practises within and adjacent to the Lukuledi riparian ecosystems

Variable	Midstream (Cluster II)	Downstream (Cluster III)	Downstream (Cluster IV)	P-value
Chemical Pest Control	81	81	72	0.609
Crop rotation	24	37	35	0.437
Fertiliser Use (Inorganic)	54	57	48	0.781
Fertiliser Use (Organic)	46	46	68	0.115
Grazing System (Free Range)	16	20	48	0.004
Grazing System (Zero Grazing)	8	7	6	0.951
Intercropping	24	57	52	0.009
Irrigation Use (Basin)	89	74	87	0.139
Irrigation Use (Furrow/canal)	76	72	61	0.415
Mechanical Pest Control	54	57	48	0.749

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Variable	Midstream (Cluster II)	Downstream (Cluster III)	Downstream (Cluster IV)	P-value
Mixed Cropping	78	70	74	0.664
Monocropping	68	65	55	0.521
Shifting Cultivation	27	52	55	0.031

Crops Grown and Livestock Kept

The study revealed that smallholder farmers engage in diverse farming practices, cultivating various crops and raising livestock.

Table 6: Common Crops Grown and Livestock Kept

Crop grown	Number of respondents	Percentage
Maize	98	86.0
Rice	41	36.0
Cowpeas	71	62.3
Pigeon Peas	65	57.0
Sweet Potatoes	16	14.0
Cassava	77	67.5
Banana	30	26.3
Vegetables	59	51.8
Sorghum	16	14.0
Cashew-Nuts	86	75.4
Sesame	80	70.2
Coconuts	70	61.4
Livestock		
Cattle	38	33.3
Goat	33	28.9
Sheep	26	22.8

Influence of farming practises within and adjacent to the Lukuledi riparian ecosystems on the water quality

The physicochemical parameters of water in the Lukuledi River varied between clusters along the river continuum (Table 7). The pH in the upstream Cluster I was lower (5.2 ± 0.54) compared to the midstream Cluster II sampling points (7.4 ± 0.26) and downstream sampling points in clusters III and IV (7.6 ± 0.27) and (7.7 ± 0.53), respectively. Kruskal-Wallis test showed a statistically significant difference in the pH of water between upstream and downstream (p = 0.000001). Further pairwise Wilcoxon test showed a significant difference between upstream Cluster I and midstream Cluster II (p = 0.000001), upstream Cluster I and downstream Cluster III (p = 0.000001) and upstream Cluster I and downstream Cluster IV (p = 0.000003). However, no significant difference was observed between midstream Cluster II and downstream Cluster III (p = 0.14), midstream Cluster II and downstream Cluster IV (p = 0.22) and downstream Clusters III and IV (p = 0.93).

The Dissolved Oxygen (DO values were higher in downstream Clusters III (5.02 ±1.02mg/L and IV (5.5 ± 1.46 mg/L) than in upstream Clusters I (4.4± 2.11mg/L) and II (4.5± 1.51mg/L). Although the values differed between sampling clusters, the Kruskal-Wallis H test shows no statistically significant difference across the river (p = 0.331).

The Electrical Conductivity of water (EC values) was higher in downstream Clusters III (316 ± 7.75 µS/cm) and IV (337 ± 6.68 µS/cm) compared to upstream Clusters I (172± 13.23µS/cm) and II

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(279± 22.10µS/cm). Kruskal-Wallis test showed statistically significant differences in the Electrical Conductivity of water between upstream and downstream (p = 0.000001). Further pairwise Wilcoxon tests showed a significant difference between upstream Cluster I and midstream Cluster II (p = 0.000218), upstream Cluster I and downstream Cluster III (p = 0.000216), upstream Cluster I and downstream Cluster IV (p = 0.000217). A significant difference was also observed between midstream Cluster II and downstream Cluster III (p = 0.00028), midstream Cluster II and downstream Cluster IV (p = 0.000218), downstream Clusters III and IV (p = 0.000278).

The Total Dissolved Solids (TDS values) was higher in downstream Clusters III (641.6 ± 112.54 mg/L) and IV (896 ± 851.87 mg/L) compared to upstream Clusters I (132.3± 1.77mg/L) and II (596.1± 20.23mg/L). Kruskal-Wallis test showed a statistically significant difference in the Total Dissolved Solids of water between upstream and downstream (p = 0.000169). Further, pairwise Wilcoxon test showed a significant difference between upstream Cluster I and midstream Cluster II (p = 0.00184), upstream Cluster I and downstream Cluster III (p = 0.00002), upstream Cluster I and downstream Cluster IV (p = 0.00163). However, no significant difference was observed between midstream Cluster II and downstream Cluster III (p = 0.261), midstream Cluster II and downstream Cluster IV (p = 0.971) and downstream Clusters III and IV (p = 0.277).

The values of water Temperature (T) were higher at downstream sampling points in Clusters III (29.8 ± 1.46 0C) and IV (30.3 ± 1.34 0C) compared to upstream Clusters I (25.1± 1.580C) and II (28.1± 0.680C). Kruskal-Wallis test showed a statistically significant difference in the water temperature between upstream and downstream clusters (p = 0.000001). Further, pairwise Wilcoxon test showed a statistically significant difference between upstream Cluster I and midstream Cluster II (p = 0.00003), upstream Cluster I and downstream Cluster III (p = 0.00004), upstream Cluster I and downstream Cluster IV (p = 0.00004), midstream Cluster II and downstream Cluster III (p = 0.0006). However, no significant difference was observed between midstream Cluster II and downstream Cluster III (p = 0.06) and between downstream Clusters III and IV (p = 0.38).

Table 7: Physicochemical Parameters (Mean ± Standard deviation) of Analysed Samples from Different Sampling Points of the Lukuledi River

	pH	DO (Mg/L	EC (µS/cm)	TDS (Mg/L	Temp (^{0}C)
Cluster I (Upstream)	5.2± 0.54	4.4± 2.11	172± 13.23	132.3± 1.77	25.1± 1.58
Cluster II (Midstream)	7.4± 0.26	4.5± 1.51	279± 22.10	596.1± 20.23	28.1± 0.68
Cluster III (Downstream)	7.6± 0.27	5.02 ± 1.02	316± 7.75	641.6± 112.54	29.8± 1.46
Cluster IV (Downstream)	7.7± 0.53	5.5± 1.46	337± 6.68	896.2±851.87	30.3± 1.34
TBS	6.5 - 8.5	5 – 7	1500	1000	20 – 25
WHO	6.5 - 8.5	8 – 10	1500	500	20 - 25

Correlation between Farming Practices and Water Quality

There was a strong positive correlation between various farming practices, including shifting cultivation, intercropping, monocropping, mixed cropping, basin irrigation, furrow irrigation, free-range grazing, use of organic and inorganic Fertilisers as well as mechanical and chemical pest and disease management practices, with measured water quality parameters such as pH, EC, TDS and Temperature. In contrast, DO (Dissolved Oxygen) showed a weak positive correlation with monocropping, mixed cropping, basin irrigation, furrow irrigation, free-range grazing, use of organic and inorganic Fertilisers as well as mechanical and chemical pest and disease management practices,

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but a strong positive correlation with shifting cultivation, intercropping and organic Fertiliser use. Among all farming practices, Zero Grazing demonstrated weak correlations with DO and TDS, suggesting it has a minimal impact on these water quality parameters compared to other farming practices **(Appendix 1).**

DISCUSSION

Household Demographic Characteristics

The demographic characteristics of farmer households adjacent to the Lukuledi River reveal significant implications for the adoption of different farming practices. The findings indicate that the majority of farmer household heads are males (75%), with most falling within the productive age group of 36-60 years (67% male and 64% female). This suggests a high potential for labour-intensive farming practices, as middle-aged farmers are generally more physically capable and experienced (Bidogeza *et al.*, 2009; Abate and Schaap, 2022). The farmer households' marital status varied significantly between genders, with a majority of men being married (77%), while women were more likely to be single (50%). This disparity may affect decision-making in agricultural activities, as married men often have greater access to land and resources (Mears and Blaauw, 2011).

Education levels indicate that most household heads have at least primary education (51% male and 68% female), which can facilitate the adoption of improved farming techniques, though professional training remains low, especially among women (4%). This might hinder the adoption of modern farming techniques (Bidogeza *et al.*, 2009). Household size also plays a role in agricultural decision-making, with most male-headed households having 4-6 members (45%), while female-headed households are more concentrated in this category (75%), suggesting a higher dependency ratio among women, which may impact labor availability and farming efficiency (Mears and Blaauw, 2011; Abate and Schaap, 2022). Income levels show that most households earn between 1,000,000 and 3,000,000 TZS annually, with slightly more female-headed households falling into the lowest income level (11%). This financial constraint could limit the adoption of costly modern farming practices among women (Abate and Schaap, 2022).

Generally, these demographic factors suggest that while male-headed households may have better access to resources and labour, female-headed households may face greater challenges in adopting capital-intensive and labour-demanding farming techniques, emphasising the need for targeted agricultural support programs.

Farming practises within and adjacent to the Lukuledi riparian ecosystems

Shifting Cultivation

Shifting cultivation is widely practised by smallholder farmers in Lindi District, especially for sesame farming, due to its low input requirements and adaptability to poor soils. Farmers clear new plots of land each season, often through bush burning, and abandon them after a few years when soil fertility declines (Lokina *et al.,* 2020). This farming practice causes serious environmental degradation due to the increasing human population in the district, especially near the Lukuledi River. It often leads to deforestation, soil erosion, and increased sedimentation in nearby water bodies. In riparian zones, shifting cultivation compromises the natural buffer functions that protect water quality, disrupts aquatic ecosystems, and increases the risk of flooding and water pollution (Egbinola *et al.*, 2014).

Within the Lukuledi riparian zone and adjacent catchment, most households in downstream clusters IV (55%) and III (52%) practise shifting cultivation, compared to midstream Cluster II (27%). This difference is likely due to the greater availability of land in downstream Clusters IV and III, which enables farmers to shift and clear new virgin land once soil fertility declines. Smallholder farmers practising shifting cultivation near the Lukuledi River typically grow crops that are well-suited to the fertile soils and seasonal moisture conditions found near the river, including maize, cassava, sorghum, sweet potato, pigeon peas, cow peas and rice. Shifting cultivation practised in

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riparian and catchment areas can significantly influence water quality by altering soil structure, nutrient levels, and vegetation cover. Removing vegetation during land clearing in nearby water bodies leads to changes in water quality parameters, including pH, Electrical Conductivity and Total Dissolved Solids (Ontumbi *et al*., 2015).

Shifting cultivation in downstream areas may lead to accumulation of organic and inorganic substances in the water of the river as soil erosion and sedimentation increase due to vegetation removal, leading to changes in water quality parameters, including pH, Electrical Conductivity and Total Dissolved Solids (Tanaka *et al*., 2021). In Northeast India, shifting cultivation has been shown to increase total organic content in soils, which can leach into streams and affect aquatic ecosystems. These changes disrupt the natural filtration capacity of riparian zones, reduce water quality, and threaten aquatic biodiversity (Shubhanshu *et al*., 2024). In Kenya's Mau Forest, farming practices such as shifting cultivation along rivers influence riparian vegetation, soil, and water quality, with Total Nitrogen and pH being particularly sensitive to changes (Njue *et al*., 2016). If shifting cultivation is not managed properly, it can threaten both environmental sustainability and the livelihoods of communities depending on these ecosystems.

Crop Rotation

In Lindi district, although a few farmers practise crop rotation within the same plot to manage soil fertility and control pests and diseases, structured crop rotation is not common. Most farmers continue to rely on traditional shifting cultivation, which involves clearing new land after a few seasons rather than rotating crops systematically on the same plot (Kasu *et al*., 2019). Most smallholder farmers within the Lukuledi River catchment practise crop rotation in downstream clusters III (37%) and IV (35%), while rarely practised in midstream Cluster II (24%). Smallholder farmers in the region face challenges in adopting crop rotation practices, largely because they prefer cultivating high-value crops like sesame and cashew nuts. This focus on immediate economic returns often limits diversification, making it difficult to implement structured rotational farming practice (Kasu *et al*., 2019).

The common types of crops grown under rotation within the Lukuledi River zone and adjacent catchment include maize, sweet potatoes, cassava, sesame, cow peas, sorghum and vegetables. Crop rotation has been found to improve water quality in agricultural watersheds. Reallocating crop rotations based on soil properties can decrease total nitrogen (TN), total phosphorus (TP), and sediment losses by 15%, 14%, and 39%, respectively (Jiang *et al*., 2021). Including legumes in corn-based rotations normally decreases nitrate-N concentrations in subsurface drainage discharge (Koropeckyj-Cox *et al.,* 2021). Modelling studies have shown that introducing red clover cover crops can decrease nitrate losses by 19.6%, while buffer strips of 2m and 6m width can decrease TP losses by 12.2% and 16.9%, respectively (Taylor *et al*., 2016). These practices can maintain crop yields while improving water quality, making them valuable tools for watershed management. However, the lower adoption of crop rotation in the Lukuledi riparian zone and the adjacent catchment may accelerate soil erosion and sediment loading into the river, which impairs their water quality.

Mixed cropping

Smallholder farmers within the Lukuledi riparian zone and adjacent catchment grow multiple crops simultaneously in the same piece of land, which offers numerous benefits for sustainable agriculture. The common types of crops produced within the Lukuledi River zone and adjacent catchment are maize, cassava, sesame, cow peas, sorghum and vegetables such as tomatoes, okra and onions. Most households in the midstream Cluster II (78%) practise mixed cropping than downstream Clusters IV (74%) and III (70%). Mixed cropping in riparian zones can significantly influence water quality. Farmers prefer the practice as it maximises land use efficiency, improves overall productivity, and provides insurance against crop failure (Paudel, 2016). Studies have shown that riparian vegetation plays a crucial role in reducing

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pollutants and improving water quality in agricultural watersheds (Broetto *et al*., 2017).

Riparian areas with poor vegetation cover are associated with elevated levels of dissolved organic carbon, manganese, sulfate, and total nitrogen in waterways (Chua *et al*., 2019). Pilot studies have demonstrated that mixed plant zones, particularly those including submerged plants, are more effective in treating polluted river water compared to non-vegetated zones (Zhang *et al*., 2016). However, the impact of mixed farming on water quality can vary depending on the specific land use and management practices, with factors such as the timing of agrochemicals and fertiliser application that influence pollutant levels (Melland *et al*.,2018).

Intercropping

In the Lukuledi River, 57% of smallholder farmers highly adopted intercropping in downstream Clusters III (57%) and IV (52%), and less in midstream Cluster II (24%). This pattern of farming practice is common in areas with scarce land availability, encouraging farmers to maximise production per unit area through intercropping to enhance soil fertility and reduce risks of crop failure. The lower adoption of intercropping in midstream Cluster II is influenced by farmers' preference for monocropping or single high-value crops, making intercropping less desirable. The common types of crops produced within the Lukuledi River zone and adjacent catchment are maize, cassava, sesame, cow peas, sorghum, sesame, cashew nuts and pigeon peas. Crop intercropping can significantly influence river water quality through its impact on non-point source pollution (Yin *et al.,* 2020).

While intercropping farming practices can be environmentally benign, increased use of Fertilisers and pesticides in agriculture has led to potential river pollution (Madjar *et al*., 2024). Agricultural runoff, particularly from inorganic farming practices, has been identified as a primary cause of increased nitrogen and phosphorus compounds in rivers (Srinivas *et al.,* 2020). However, well-designed intercropping systems can efficiently use natural resources, increase biodiversity, and enhance crop productivity while reducing off-farm inputs (Altieri 2019). This approach can potentially mitigate the negative impacts of irrigated agriculture on river water quality, which has been observed in some basins (Yin *et al.,* 2020). Implementing best management practices in intercropping, such as increasing soil organic matter and using cover crops, can help improve water quality in riverine ecosystems (Srinivas *et al.,* 2020).

Monocropping

Smallholder farmers in the Lukuledi River adopted monocropping in midstream Cluster II (68%) and downstream Cluster III (65%), with less adoption in downstream Cluster IV (55%). High adoption of monocropping by farmers is due to specialisation in single crops for market sales. Farmers in this region often prefer monocropping for cash crops with higher market value, such as cashew nuts, sesame, pigeon pea, and rice, vegetables such as onions and tomatoes, and cassava (Mashindano & Kihenzile2013). Although continuous cropping of the same plant species depletes specific nutrients, requires high use of Fertilisers and pesticides to maintain productivity and encourages the proliferation of crop-specific pests and diseases (Mihrete & Mihretu, 2025). Repeated use of pesticides and Fertilisers in monocropping systems can result in the accumulation of toxic residues in nearby water bodies, further degrading water quality and posing risks to human and ecosystem health (Belete & Yadete 2023).

Research indicates that Monocropping in riparian zones significantly impact water quality in adjacent rivers (Hossien & Yousif 2024). Monocropping in these areas can lead to increased nutrient loads, particularly nitrogen and phosphorus, in surface runoff and subsurface flow that negatively affect the water quality of nearby rivers by increasing the risk of soil erosion, nutrient runoff, and chemical leaching (Hossein & Yousif 2024). This nutrient loading promotes eutrophication, which depletes oxygen in the water and harms aquatic life. Without the biodiversity provided by crop rotation or natural vegetation, the soil becomes less resilient,

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leading to increased loss of topsoil and nutrients, especially nitrogen and phosphorus, that are easily washed into rivers during rainfall (Zou *et al.,* 2024). This nutrient loading promotes eutrophication, which depletes oxygen in the water and harms aquatic life.

Free Range Grazing

Smallholder farmers within and adjacent Lukuledi riparian ecosystem commonly practise free-range grazing, with the highest prevalence observed in downstream Cluster IV, where 91% of farmers engage in the practice. This is followed closely by midstream Cluster II at 88%, while a slightly lower proportion, 82%, was recorded in downstream Cluster III. The common livestock grazed in this practice includes cattle, goat and sheep. The prevalence of this practice in Cluster IV is due to more open land, allowing livestock to graze freely with fewer restrictions from crop farming and reducing the need for feeding structures and purchased fodder. This practice requires less labour but needs larger land areas and is common in regions with ample open space (Kubkomawa & Usman, 2021). While it can provide nutrient-dense diets for ruminants and contribute to biodiversity conservation, overgrazing can lead to soil erosion, water pollution, and desertification (Weber & Horst, 2011; Michalk *et al.,* 2019).

The increasing livestock populations in the Lukuledi riparian ecosystem and continued human pressure have resulted in the shrinking of grazing lands and threaten the ecological integrity of the riparian ecosystem, with far-reaching consequences for both people and nature (Michalk *et al.,* 2019). To mitigate negative impacts, experts recommend implementing semi-intensive or intensive systems for commercial production, utilising crop residues and agro-industrial by-products, and combining grazing with other practises like mowing (Kim, 2018). Proper management of stocking rates and grazing duration is crucial for maintaining pasture health and productivity (Kubkomawa & Usman, 2021).

Zero Grazing

Farmers within the Lukuledi riparian zone and adjacent catchment practise zero grazing. The practise involves a livestock management approach where animals especially cattle are confined and provided with harvested fodder, ensuring benefits such as enhanced diet regulation and minimized soil erosion, reducing animal trampling and minimizes surface water pollution (Haile, 2018). The adoption rate of this practise among smallholder farmers in the Lukuledi riparian zone and adjacent catchment is generally low, with the highest rate observed in midstream Cluster II at only 8%, followed by 7% in downstream Cluster III and the lowest in downstream Cluster IV at 6%. This limited adoption can be attributed to several factors, including a lack of resources such as labour, capital to construct and maintain zero grazing units, as well as limited access to training and extension services (Kabebe, 2015).

Additionally, cultural preferences for free-range grazing and the perceived higher costs and labor demands of zero grazing discourage many farmers from embracing the practise (Kabebe, 2015). Most smallholder farmers struggle with these costs and lack awareness of benefits accrued from the practise including productivity improvement by controlling diet and reducing disease. In Tanzania, smallholder dairy farming incorporating zero grazing is viewed as a viable alternative to extensive herding, with the potential to yield higher outputs and ensure stable incomes. However, achieving maximum benefits necessitates proper infrastructure and adequate support services (Franzluebbers *et al.,* 2012). In Ethiopia, zero grazing is regarded as a viable strategy to mitigate feed shortages and enhance productivity in highland regions (Haile, 2018). It represents a shift from conventional livestock rearing to an emphasis on quality and efficiency, particularly in dairy farming. Nonetheless, zero grazing poses challenges, including higher costs, greater time commitments, and the need for specialised knowledge (Holohan *et al*., 2021).

Irrigation farming practise

In Lindi District, irrigation is practised primarily by smallholder farmers to supplement rainfall and

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enhance agricultural productivity, particularly during dry seasons or irregular rainfall patterns (Kangalawe & Lymo 2013; Kulyakave *et al*., 2023). The dominant methods include traditional furrow and basin irrigation, with some use of modern techniques such as motorised pumps along riverbanks, especially near the Lukuledi River (Kangalawe & Lymo 2013). These irrigation efforts support the cultivation of crops like vegetables, rice, and maize. However, the expansion of irrigation is often limited by inadequate infrastructure, high costs of water pumping equipment, and limited technical knowledge among farmers. Despite these challenges, irrigation remains vital for improving food security and sustaining livelihoods in the region, especially in response to increasing climate variability (Kulyakave *et al*., 2023).

Farmers within and adjacent to the Lukuledi riparian ecosystem practise basin irrigation by 89% followed by furrow/canal irrigation by 76%, in midstream Cluster II while in downstream cluster III, 74% of smallholder farmers practise basin irrigation and 72% furrow/canal irrigation. On the other hand, in downstream cluster IV, farmers practise basin irrigation by 87% and 61% furrow/canal irrigation. Basin irrigation, suitable for crops like rice and vegetables, involves flooding enclosed areas, while furrow irrigation uses trenches between crop rows and is suitable for crops like maize (Walters & Jha, 2016). Both methods have advantages and challenges. Furrow irrigation can be more efficient than basin irrigation for certain crops, offering better water distribution and disease control (Walters & Jha, 2016). However, both methods can lead to soil salinisation and changes in the physicochemical properties of water if not managed properly (Munishi *et al*., 2011; Irfan *et al.,* 2014). Improving irrigation practises is crucial for sustainable agriculture, especially in water-scarce regions (Walters & Jha, 2016).

Use of Fertilisers for Soil Fertility Management

In Lindi District, farmers are increasingly adopting organic Fertilisers to enhance soil fertility and boost crop production. Despite this positive trend, the overall application rate of both organic and inorganic Fertilisers remains relatively low compared to other regions in Tanzania. Nonetheless, there is a growing interest among farmers in using organic manure such as compost and animal waste, alongside synthetic Fertilisers, indicating a shift toward more nutrient-conscious farming practices (Mongelli *et al.,* 2022). With declining soil quality and the need to support growing food demands, farmers integrate traditional compost, manure with modern chemical inputs to enhance nutrient availability in their fields (Selim 2020). Organic manure application is most prevalent in downstream Cluster IV (68%), and is less adopted in midstream Cluster II and downstream Cluster III, with 46% of smallholder farmers. The higher use of organic manure in downstream Cluster IV is likely due to greater livestock numbers, ensuring a steady manure supply. Additionally, organic manure is often preferred in less fertile soils and traditional farming practices, though its labour-intensive transportation and application limit widespread adoption in more commercialised areas. In contrast, Inorganic Fertilisers application is most predominant in downstream Cluster III (57%), followed by midstream Cluster II (54%) and is less adopted in downstream Cluster IV (48%) of smallholder farmers.

The higher adoption in Clusters II and III suggests a greater emphasis on commercialised farming, where synthetic Fertilisers help maintain productivity in nutrient-depleted soils. In contrast, Cluster IV's reliance on organic manure aligns with its strong livestock presence and a more subsistence-based farming system with limited capital investment in agrochemicals. The common types of inorganic Fertilisers used include NPK compounds, urea, and ammonium nitrate. While inorganic Fertilisers effectively address nutrient deficiencies and enhance crop productivity, excessive use can contribute to soil acidification, nutrient runoff, and environmental pollution. Organic farming practices can help protect water quality by reducing nutrient leaching, water runoff, and soil erosion (Sivaranjani & Rakshit, 2019).

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However, inorganic farming practices have been shown to have a direct negative impact on river water quality, with positive correlations between double-crop cover and build-up areas and various water quality parameters (Srinivas *et al*., 2020). Organic and inorganic Fertilisers play crucial roles in soil fertility management and crop productivity. Organic manures, such as farmyard manure and compost, improve soil structure, increase organic matter content, and enhance long-term soil health (Wato *et al*., 2024). Inorganic Fertilisers provide readily available nutrients for immediate plant uptake but can lead to soil degradation if used excessively (Mahmood *et al.,* 2017). Combining organic and inorganic Fertilisers has shown promising results, improving soil physico-chemical properties and crop yields (Mahmood *et al*., 2017). Organic farming practices have demonstrated long-term benefits, including increased soil organic carbon and higher profitability compared to inorganic farming (Mahmood *et al*., 2017).

Pest and Disease Management

Household farmers within the Lukuledi riparian zone and adjacent catchment utilised a combination of mechanical and chemical methods to manage pests and diseases that pose a threat to their crops. Mechanical methods were widely adopted due to their affordability and ease of application. These include hand-picking pests, setting traps, removing diseased plant parts, using tillage to disrupt pest life cycles, planting resistant crop varieties, maintaining field sanitation, and practising crop rotation (Adhikari 2022). Together, these approaches help reduce pest populations and limit the spread of diseases, supporting healthier crop yields with minimal environmental impact (Adhikari 2022). This environmentally friendly approach minimises chemical exposure and helps maintain soil and ecosystem health. However, it can be labour-intensive and requires constant monitoring.

The practice is most common in downstream Cluster IV (68%), followed by midstream Cluster II (46%), and downstream Cluster III (46%). The higher adoption of mechanical pest and disease control in downstream Cluster IV may be due to the availability of labour, and farmers rely on cost-effective control measures. Conversely, lower adoption in midstream Cluster II and downstream Cluster III is attributed to limited knowledge, lower labour availability, or preference for alternative pest control strategies (Khan & Damalas, 2015; Riwthong *et al*., 2017). However, to ensure more effective and timely protection of their crops, many farmers also turn to chemical pesticides and fungicides, which can be in the form of powdery or liquid, commonly used in cashew nuts to control powdery mildew during the flowering season (Kitali & Malekela, 2021). This method provides rapid action against severe infestations, requires less labour than mechanical methods, and is more efficient for large-scale farming.

However, concerns include environmental impacts, the development of pest resistance, harm to beneficial organisms, and potential health risks from chemical residues (Adhikari, 2022). Chemical pest control is widely adopted across all clusters, with the highest usage in midstream Clusters II and downstream Cluster III (81%), while farmers in downstream Cluster IV have a lower adoption rate (72%), due to a greater reliance on mechanical measures of pest and disease control. The higher use of chemical control in midstream Cluster II and downstream Cluster III suggests an economic condition and farmers' awareness to improve their production towards a market-oriented approach, where maximising productivity is essential (Omolehin *et al*., 2007).

In contrast, lower pesticide use in downstream Cluster IV may reflect traditional farming practices, affordability constraints, or environmental conservation efforts (Adhikari 2022). This trend indicates that commercial farming systems in midstream Clusters II and downstream III prioritise efficiency in pest and disease management, whereas Cluster IV leans toward more diversified or subsistence-based approaches. The intensive use of pesticides in agriculture poses a threat to river ecosystems, contaminating water, sediments, and fish (Maurya & Malik, 2016). Pesticide runoff can negatively impact soil and river water quality in agricultural

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areas (Dhaifulloh *et al.,* 2024). To mitigate these effects, various control techniques can be employed, including chemical, biological, mechanical, and cultural methods (Maurya & Malik, 2016). Additionally, riparian vegetation plays a vital role in protecting and improving chemical water quality in streams (Dosskey *et al*., 2010). Proper pesticide management, sustainable agricultural practices, and farmer education are essential for reducing the negative impacts on water quality (Dhaifulloh *et al*., 2024).

Influence of farming practises within and adjacent to the Lukuledi riparian ecosystems on the water quality

The quality of water differed among clusters and across sampling sites along the Lukuledi River. Generally, the physicochemical parameters of water were within the acceptable ranges of water quality for aquatic life forms and domestic use. However, pH, DO and Temperature in some sampling Clusters deviate from the TBS and WHO established standards for drinking water. In water quality assessment, pH is a crucial factor as it affects aquatic life, irrigation, industrial and drinking water suitability. The pH range from 6.5 to 8.5 is recommended for drinking water (WHO, 2008; TBS, 2008). Water with too acidic or alkaline levels can impact the solubility and toxicity of various chemicals in water, making them harmful or stressing aquatic organisms in terms of their growth, reproduction and survival (Mbaruku, 2016). Too acidic or alkaline water usually tests unpleasant and corrodes plumbing systems, leaching harmful metals and nutrients into the supplied water (Mbaruku, 2016).

In the Lukuledi River, the pH of the water varied across the different sampling points, showing a gradual change from the upstream Cluster I to the downstream Cluster IV in an increasing trend. The pH of water in midstream Cluster II and in downstream Clusters III and IV were within the set standards by TBS and WHO for drinking water. In upstream Cluster I of the Lukuledi River, the water pH was 5.2, which is below the TBS and WHO set standards. However, the water is still fit for use. It is said that water becomes unfit for domestic use, like drinking, when its pH value is less than 4.5 or exceeds 9 (Rajabu *et al*., 2024). Rajabu *et al*. (2024) found higher pH in upstream sampling sites than downstream sampling sites of the Pinyinyi River in Ngorongoro district, influenced by various anthropogenic activities.

This trending result was different from the Lukuledi River where lower pH was found in the upstream sampling points and higher in the downstream sampling sites but similar to Likens *et al*., 2006; Sharma *et al*., 2014 who reported lower pH in upper section of the river was due to natural factors like the decomposition of huge organic matter, hydrologic flow path and the presence of geological influences that release acidic compounds. Higher pH at the downstream sampling points in Clusters 3 and 4 are due to the dilution of acidic substances in water due to the increasing volume of water as more tributaries and springs join the river and reduce the concentration of acidic compounds as well as agricultural runoff containing lime and other alkaline substances that can also increase the pH of water downstream (Razali *et al*., 2020).

In the Lukuledi River, the DO of the water differed across the different sampling clusters, showing variation from the upstream Cluster I to the downstream Cluster IV. Lower Dissolved Oxygen (DO) values were recorded in the upstream Cluster and midstream Cluster II sampling sites. These values were below the set standards for drinking water by TBS (2008) and WHO (2008). The levels of dissolved oxygen could be due to factors such as increased biological activities, low diffusion and low solubility (Kulkarni, 2016). The higher DO values were measured in the downstream Clusters III and IV, which are within the set standards by (TBS, 2008) but below the standard set by (WHO, 2008). This could be related to increased volume of inflow to the river, dilution by precipitation and increased discharge of water in the river as more tributaries join the river downstream (Razali *et al.,* 2020).

For the aquatic dwellers, the acceptable levels of Dissolved Oxygen range from 6mg/L in warm water to 9mg/L in cold water (Rajabu *et al*., 2024).

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Generally, higher levels of dissolved oxygen show good water quality that assists the survival of diverse aquatic organisms, while low levels can harm, stress and sometimes to the death of organisms (Kulkarni, 2016). Farming practices significantly influence dissolved oxygen (DO) levels in water bodies. Nutrient runoff from agricultural activities, particularly nitrogen and phosphorus, can lead to eutrophication and reduced DO (Turpin *et al.,* 1996). Trout farm effluents have been shown to impact water quality parameters, including DO, and affect benthic macroinvertebrate communities downstream (Karimi *et al*., 2016). Best Management Practices (BMPs) in agriculture, such as constructed wetlands and nutrient management, can mitigate pollution and improve DO levels in impaired watersheds (Kannan *et al*., 2014).

In water-logged areas, integrated rice-shrimp farming practices can provide economic benefits but may contribute to pollution and eutrophication issues (Jayan & Sathyanathan, 2010). Sustainable farming approaches and proper management of soil, water, and crops are essential to maintain water quality and DO levels in agricultural watersheds. Implementing BMPs and regulating resource use can help mitigate the negative impacts of farming practices on water quality and aquatic ecosystems.

The electrical conductivity of water is the capability of water to conduct an electrical current. This ability depends directly on the concentration of conductive ions in the water as a result of dissolved salts, minerals and other inorganic substances (Belov *et al*., 2019). The Electrical Conductivity of water (EC values) was higher in downstream Clusters III (316 ± 7.75 µS/cm) and IV (337 ± 6.68 µS/cm) compared to upstream Clusters I (172± 13.23µS/cm) and II (279± 22.10µS/cm). These values were within the permissible range. The electrical conductivity of water gives valuable insights into the mineral content of water, which has effects on the suitability of water for various uses. For agricultural activities, electrical conductivity helps to determine the suitability of water for irrigation, as high mineral content can harm crops (Subramani *et al*., 2005). For industries, conductivity is monitored to ensure the quality of water for the processes and to prevent corrosion or scaling in equipment, while for drinking water testing of conductivity aids in the identification of contaminants for treatment planning (Yogendra & Puttaiah, 2008). The geology of the area through which water flows has an effect on the electrical conductivity of water in streams and rivers (APHA, 1992).

Different studies conducted on inland freshwater bodies reported that conductivity levels lying between 150 and 500 µS/cm support the life of various species of fisheries (APHA, 1992). Conductivity outside this range indicates its non-suitability for fish and other macroinvertebrates. In the United States conductivity of rivers mostly lies between 50 to 1500 µS/cm (APHA,1992). The study conducted in five coastal rivers of Tanzania, including Wami, Pangani, Ruvu, Zigi and Kizinga, found that to have electrical conductivity ranging from 141.7µS/cm to 320.4 µS/cm (Mihale, 2022). The higher Electrical Conductivity recorded downstream sampling points than upstream sampling points could be due to the gradual accumulation of dissolved ions and other conductive substances as water flows downstream. Runoff from agricultural areas introducing Fertilisers and other chemicals, urban runoff adding pollutants, as well as natural erosion and dissolution of minerals from surrounding soil and rocks, could contribute to the increased conductivity downstream (Razali *et al*., 2020).

Total dissolved solids show the capacity of water to dissolve various organic and inorganic minerals or nutrients like Potassium, Sulphate, Calcium, Carbonates and Bicarbonates. The Total Dissolved Solids (TDS values) were higher in downstream Clusters III (641.6 ±112.54mg/L and IV (896 ± 851.87 mg/L) compared to upstream Clusters I (132.3± 1.77mg/L) and II (596.1± 20.23mg/L). These values were within the permissible range. TDS is a crucial variable in water quality assessment, determining the combined content of all organic and inorganic substances existing in water as molecules, ionised or in suspended form

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(Mbaruku, 2016). The importance of measuring TDS lies in its ability to show the mineral content of the water that affects its taste, hardness and suitability for different uses.

Water is said to be palatable and considered good for drinking when with a total dissolved solids level of less than 600mg/L and becomes unpalatable when with total dissolved solids that exceed 1000mg/L (Kuutondokwa, 2008). High TDS levels cause scaling in pipes and appliances and corrosion of equipment in industries. It also affects the life of aquatic ecosystems (Bartram, 2009). Total dissolved solids are lower upstream and increase downstream along the river system due to the gradual accumulation of dissolved minerals and other substances entering the stream from tributaries joining the main stream from agricultural landscapes and urban areas (Razali *et al*., 2020).

The mean temperatures in the upstream Cluster I sampling points were within the permissible range as per TBS and WHO standards. Higher temperature values that are above the TBS and WHO set standards were recorded in midstream Cluster II and downstream Clusters III and IV sampling points. This result indicates increasing human pressure on the river system as it flows downstream, leading to elevated water temperatures beyond acceptable standards. The changes may reflect degradation of riparian habitats due to land use changes in downstream clusters. This pattern of temperature variation across sampling points was expected due to existing riparian vegetation cover upstream, which leads to a decrease in temperature as vegetation reduces the solar radiation reaching the water directly, as it happens downstream in agricultural landscapes where riparian vegetation has been removed for farming.

This trend could also be due to changes in elevation gradient from upstream to downstream (Alavaisha *et al*., 2019; Dimri *et al*., 2022). Temperature measurement is an important water quality parameter as it influences numerous physical, chemical and biological processes in aquatic ecosystems (Machena, 1997). It has effects on the solubility of gases, including oxygen. Warmer water typically has lower dissolved oxygen than cold water and this can stress the life of aquatic organisms. Temperature also affects the rate of chemical reactions and metabolic processes of aquatic dwellers (Rajabu *et al*., 2024). Temperature has impacts on water density, stratification and mixing patterns in water bodies that alter habitat suitability for different species and affect the overall health and diversity of aquatic ecosystems (Zhang *et al*., 2015). Cool water is more palatable than warm water as temperature enhances the growth of microorganisms that may increase problems related to taste, odour, colour and corrosion (Johnson *et al*., 2024).

Correlation between Farming Practices and Water Quality

The correlations observed between farming practices and water quality parameters show a revealing picture of how farming practices can significantly influence aquatic environments. This trend is mainly critical in regions where farming practices are concentrated near water sources. The positive correlation between farming practices and water quality parameters like pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and temperature indicates that these activities are altering the physical and chemical properties of water in ways that may be detrimental to aquatic life and ecosystem health in general (Sulaiman *et al.,* 2023).

Farming practices such as monocropping and mixed cropping regularly depend heavily on chemical inputs, including synthetic Fertilisers and pesticides. When these agrochemicals are applied excessively or during inappropriate seasons, they are easily washed into nearby streams through surface runoff, particularly during rainfall (Akamagwuna, 2021). This runoff increases nutrient loading, especially nitrogen and phosphorus, leading to eutrophication, a process that promotes excessive algae growth, depletes oxygen, and disrupts aquatic habitats (Alavaisha *et al*., 2019). The elevated EC and TDS values associated with farming practices reflect increased concentrations of ions, salts, and dissolved solids in

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the water, often derived from Fertiliser residues, eroded soil particles, and animal waste (Zalidis *et al*., 2002). Furrow and basin irrigation techniques can aggravate this by promoting water percolation and solute transport into drainage systems, especially in areas with poor water management or soil conservation practices (Zalidis *et al*., 2002).

Temperature increases in water bodies are also linked to farming practices, especially when vegetation cover is removed for cultivation. Loss of riparian vegetation exposes water surfaces to direct sunlight, raising water temperatures. Warmer water holds less dissolved oxygen, accelerates microbial activity, increasing the rate of organic matter decomposition, further stressing aquatic organisms (Machena, 1997; Alavaisha *et al.,* 2019). In contrast, Dissolved Oxygen (DO) showed a strong positive correlation with farming practices such as shifting cultivation, intercropping, and the use of organic Fertilisers. Shifting cultivation and intercropping promote soil cover, reduce erosion, and enhance organic matter content, which improves water retention in soils and reduces the speed and volume of runoff. Organic Fertilisers, unlike chemical ones, release nutrients more slowly and improve soil structure, thus lowering the likelihood of nutrient leaching.

These practices contribute to more stable and biologically balanced aquatic environments where DO levels are relatively higher, supporting diverse aquatic fauna (Alavaisha *et al.,* 2019; Sulaiman *et al*., 2023). The weak positive correlations between DO and practices such as free-range grazing, furrow irrigation, and chemical pest management advocate a minimal harmful result on oxygen levels. Free-range grazing near water bodies leads to trampling, vegetation destruction, and faecal contamination, all of which can increase biochemical oxygen demand (BOD) and reduce DO over time. Chemical pest control, through runoff, introduces toxins that disrupt aquatic microbial communities, which play a role in natural oxygen cycling (Alavaisha *et al*., 2019).

A weak positive correlation between zero grazing with DO and TDS indicates a minimal environmental footprint on water quality, highlighting its potential as a best practice for sustainable livestock management. By confining animals away from water bodies, zero grazing reduces direct pollution, limits overgrazing, and helps maintain vegetative buffers that filter runoff. Moreover, the controlled collection and management of manure from zero-grazed animals can be used constructively as organic Fertiliser, further closing nutrient loops and supporting soil and water conservation (Lyon *et al*., 2019; Holohan *et al*., 2021). These insights emphasise the urgent need to transition toward more sustainable farming practices such as zero grazing, organic fertilisation and intercropping that could substantially improve water quality and ecosystem integrity.

CONCLUSION

This study assessed the influence of farming practices on the water quality of the Lukuledi River in Lindi District.

Generally, the study revealed different farming practices within and adjacent to the river catchment, including shifting cultivation, intercropping, monocropping, mixed cropping, irrigation farming, especially basin and furrow irrigation, free-range and zero grazing practices, use of organic and inorganic Fertilisers for soil fertility management, and the use of pesticides for pest and disease management in their farms.

The measured physicochemical water quality parameters, such as pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Temperature (T), were generally higher in downstream sampling points compared to the relatively undisturbed upstream sections. However, pH values were below the set standards by TBS and WHO in upstream Cluster I, while in midstream Cluster II and downstream Clusters III and IV, the values were within TBS and WHO standards. Similarly, DO values in upstream Cluster I and midstream Cluster II were below the TBS standards, while the acceptable values were observed in downstream Clusters III and IV. However, the measured DO values were below the acceptable ranges by WHO across all the sampling points. On the other hand, the temperature in

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upstream Cluster I was within the acceptable range by TBS and WHO, while the higher temperature values above the acceptable ranges were found in midstream Cluster II and downstream Clusters III and IV. The EC and TDS were within the range by TBS and WHO across all sampling clusters.

There was a strong positive correlation between the farming practices and physicochemical parameters of water quality, indicating the influence of farming on water quality. Zero Grazing exhibited weak correlations with DO and TDS, indicating that it has minimal impact on water quality parameters. These findings generally suggest that most farming practices alter key environmental variables, which in turn impact aquatic life and disrupt ecosystem functions.

Recommendation

The findings indicate that farming practices negatively impact the water quality of the Lukuledi River.

To mitigate these effects, it is crucial to implement sustainable agricultural practices, including riparian buffer zones to filter pollutants, integrated pest management to reduce chemical inputs, and soil conservation techniques like contour farming and tree planting to prevent erosion and sedimentation.

Improved irrigation management can minimise water wastage and contamination, while installing water troughs or adopting zero-grazing practices can protect stream banks from livestock damage.

Educating farmers on sustainable practices is essential for long-term river health, alongside continuous monitoring of farming activities and regular water quality assessments. Since this study was conducted during the wet season, further research during the dry season is recommended to better understand seasonal variations in water quality.

Declaration on Conflict of Interest

The authors affirm that there are no conflicts of interest associated with this study.

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Appendix 1: Correlation between Farming Practices and Water Quality of the Lukuledi River

Variable	SC	IC	MC	MX	BI	FI	FRG	ZG	OM	IOM	MPC	CPC	pH	Do	EC	TDS	T
Shifting cultivation (SC)	1	.990**	0.794	0.833	0.815	0.803	0.865	0.778	0.916	0.844	0.844	0.836	0.917	0.919	.978*	0.933	.994**
Intercropping (IC)		1	0.769	0.789	0.761	0.777	0.818	0.814	0.854	0.825	0.825	0.809	0.883	0.909	0.947	0.874	.972*
Monocropping (MC)			1	.984*	.972*	1.000**	.972*	0.905	0.856	.996**	.996**	.997**	.963*	0.495	0.879	0.824	0.844
Mixed cropping (MX)				1	.998**	.987*	.997**	0.835	0.928	.982*	.982*	.990**	.985*	0.573	0.923	0.901	0.886
Basin irrigation (BI)					1	.975*	.996**	0.795	0.936	.967*	.967*	.979*	.976*	0.561	0.915	0.907	0.873
Furrow irrigation (FI)						1	.976*	0.902	0.865	.997**	.997**	.998**	.968*	0.508	0.887	0.833	0.853
Free range grazing (FRG)							1	0.821	.952*	.975*	.975*	.983*	.992**	0.627	0.946	0.93	0.914
Zero grazing (ZG)								1	0.671	0.923	0.923	0.902	0.854	0.498	0.791	0.652	0.788
organic manure (OM)									1	0.875	0.875	0.887	.956*	0.788	.973*	.997**	.952*
Inorganic manure (IOM)										1	1.000**	.999**	.977*	0.565	0.912	0.849	0.885
Mechanical pest control (MPC)											1	.999**	.977*	0.565	0.912	0.849	0.885
Chemical pest control (CPC)												1	.980*	0.557	0.912	0.86	0.881
pH													1	0.701	.974*	0.941	.953*
DO														1	0.844	0.832	0.883
EC															1	.976*	.995**
TDS																1	.962*
Temperature (T)																	1

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

