Implication of climate change and variability on stream flow in Iringa region, Tanzania

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ABSTRACT

This paper investigates the implication of climate change and variability on the river flow within the traditional irrigation farming system, *vinyungu*, in Iringa region, Tanzania. The study aimed at establishing areas that are most impacted by climate change in terms of river flow and various adaptation strategies. It is based on both primary data collected by questionnaires distributed randomly among 189 farmers and key informant checklists conducted with villages' leaders and Agriculture Extension Officers. Two focused group discussions were carried out for each village as well as the researcher's own observations, and secondary data includes: literature review, rainfall and river flow data. The long-term annual trends of rainfall and river flow were analyzed via Mann–Kendall's statistical test and linear trend analysis. Climate data on rainfall trend showed a significant decreasing pattern during the last 17 years. Also, river flow data showed a slight decline within the same period. Decrement in river flow, combined with rainfall fluctuation, forced farmers to employ various adaptation strategies. Following the severity of the problem the paper recommends that more research be conducted on proper water management for sustainable river flow for both agriculture production and environmental management.

Key words | climate change and variability, Iringa Rural District, stream flow, *vinyungu*

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INTRODUCTION

Agriculture remains the mainstay of the economy of many sub-Saharan Africans and central to the survival of millions of people (FAO 2004). It provides employment to an average of 65% and contributes to about 32% of the GDP (AASR 2013). In Tanzania, the sector contributes to about 50% of GDP, 80% of employment, and 75% of export (AASR 2013). Despite being crucial to the economy of the continent and the country in particular, it is among the main sectors affected by climate change and variability (CC&V) and its associated impacts (Kandji *et al.* 2006; Mary & Majule 2009). The negative effects of CC&V on agriculture include unreliable rainfall pattern, the decline in rainfall amount, drought, floods, and outbreak of crop pests and diseases (URT 2012). To reduce vulnerability levels, indigenous farmers have adopted various coping strategies aimed at improving storage and utilization of water resources. These include various techniques of water harvesting and utilization in sustaining crop yields (Majule & Mwalyosi 2005; Kassian 2012). The same techniques of traditional irrigation conducted by using shallow canals are practiced in the northern state of Himachal Pradesh (Gover *et al.* 2013).

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Those techniques have different names in different localities, including, for example, *kuhls* in the northern state of Himachal Pradesh, India (Gover *et al.* 2013) and *ngoro* or *matengo* pit in Ruvuma region (Sims *et al.* 1999; Yanda *et al.* 2005), *majaluba* in Mara region (FAO 2001; Yanda *et al.* 2005), *ndiwa* in west Usambala mountains (Sokoni & Sechambo 2005) and '*vinyungu*' in Iringa and Njombe regions (Majule & Mwalyosi 2005) practiced in Tanzania.

The *vinyungu* system is practiced in areas that are moist throughout the year; sometimes the system depends on water from rivers for irrigation (Majule & Mwalyosi 2005; Munishi *et al.* 2011). As a result, *vinyungu* are mostly located along rivers, around water catchments and/or within wetlands. However, even *vinyungu* systems tend to be affected by CC&V through the reduction of water level in rivers, which most farmers rely on for irrigation (Majule & Mwalyosi 2005; Magembe 2007). In addition, it tends to cause drying up of wetlands suitable for *vinyungu* farming. In most cases *vinyungu* is associated with low water use efficiency including diversion of water from river channels for irrigation and some practices that lead to the collapse of riverbanks and drying up of wetlands and downstreams (Mallango 2001). This results in the collapse of riverbanks and drying up of wetlands and downstreams. It is mainly due to this that acts and by-laws to govern the conservation, management, and development of water sources, riverbanks, and beaches or coasts have been passed (Madulu 1998; Mkavidanda & Kaswamila 2000; Kassian 2012; Kisanga 2013). Despite the fact that most farmers are aware of the acts and by-laws, they do not comply with them. Consequently, governmental and non-governmental institutions in Tanzania had either to improve or limit *vinyungu* farming.

PROBLEM STATEMENT

Even though there are various studies on *vinyungu* practice and its socio-economic importance (Mkavidanda & Kaswamila 2000; Mallango 2001; Majule & Mwalyosi 2003, 2005; Magembe 2007; Kangalawe *et al.* 2011; Pantaleo *et al.* 2011), little has been done regarding the implication of CC&V on the Lyandembera River flow used for *vinyungu* irrigation for food security and income generation in the study area. Therefore, the current study aimed at filling such a knowledge gap in Iringa Rural District by assessing the implication of CC&V on the river flow of Iringa Rural District in the southern highlands of Tanzania. The relationship between rainfall and river flow that is used for traditional irrigation and various adaptation strategies for water shortage used for irrigation were investigated. The results are envisaged to stimulate further research on proper adaptation strategies for water shortage and improvements in crop production, income generation, and river flow.

MATERIALS AND METHODS

Study area

The study was carried out in Iringa Rural District, Iringa region located in the southern highlands of Tanzania. The district is among four districts of the region lying between latitude −7 °33′50.36 and longitude 34 °52′53.73, practicing the *vinyungu* system using water from rivers for irrigation. The district has two ecological zones: the midland zone lying between 1,200 and 1,600 m above sea level (ASL) with rainfall ranging between 600 and 1,200 mm per year; and the lowland zone ranging between 900 and 1,200 m ASL receiving rainfall between 500 and 600 mm per year.

The study was conducted in the midland ecological zone that has the potential for cultivating different crops, including maize, sunflower, Irish potatoes, beans, onions, tomatoes, and various types of vegetables. This agro-ecological zone has a sub-humid climate with rainfall starting in late November or December and ending in April or May followed by the dry season. Specifically, the study was carried out during the rainy season in two selected villages, namely, Lumuli and Ifunda villages, based on market accessibility for *vinyungu* products, an ecological zone for comparison, and availability of river flow data. Comparably, Lumuli village has lower market access than Ifunda village and both villages are located in the same ecological zone and by the same river (Figure 1).

Data collection

Both primary and secondary data were used in the study. Primary data collection was undertaken using household

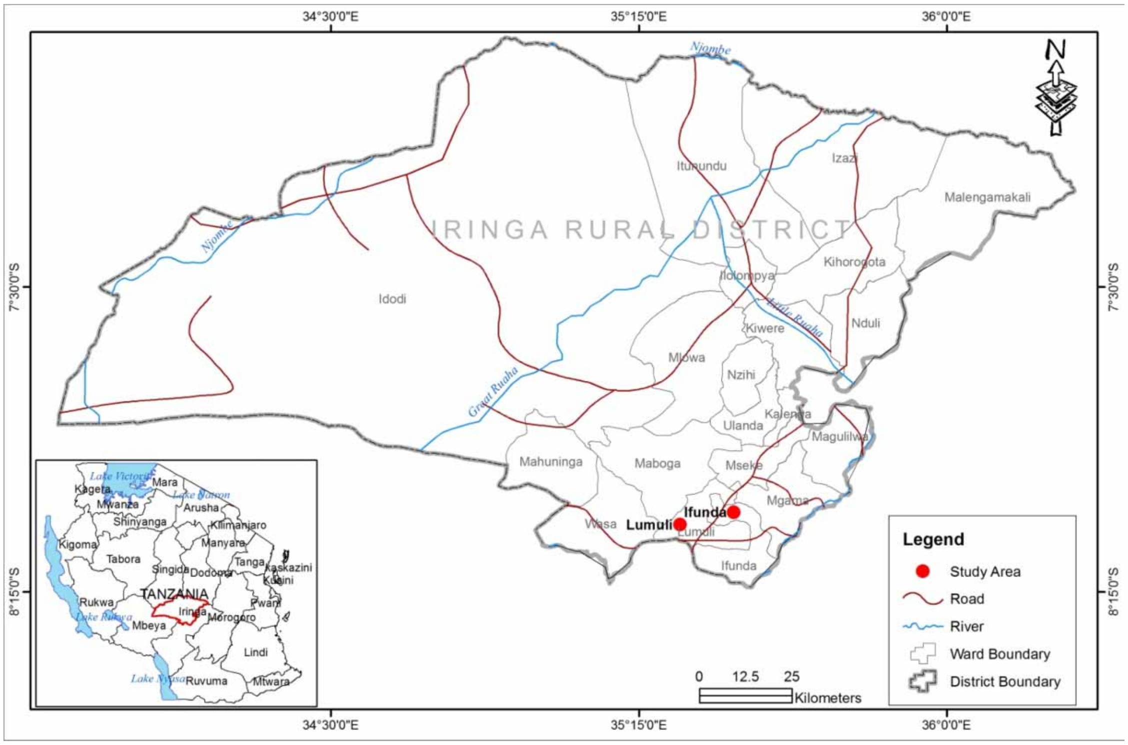

Figure 1 | Location of the study area.

questionnaire, key informants' interview, focus group discussion (FDG), and direct field observation. Several research tools were used to acquire local perceptions on the trend of rainfall and river flow, causes, indicators for the current situation in Lyandembera River, and by-laws concerning human activities along the river. One hundred and eighty-nine households, forming a sample size of 5% from each village, were surveyed during household questionnaireas recommended by Boyd *et al.* (1985). Heads of household or other members were selected strategically with the help of the Village Executive Officer (VEO). Respondents' selection was based on those aged 30 and above and practicing the *vinyungu* farming system along the Lyandembera River. The VEO, District Agricultural Officers and Agricultural Extension Officers were among the key informants to provide information, for example, village by-laws; a FGD of eight members in each village was conducted as recommended by Krueger & Casey (2000). Each group involved both males and females aged 30 years and above. This age selection was based on experience of rainfall for about 30 years and practicing *vinyungu* farming along the Lyandembera River. Key informant interviews and FGD were conducted with the aid of a checklist. Guided and unguided direct field observations were used to cross check information including information about *vinyungu* practices.

Secondary data on the farming system were obtained through a literature review. Climatic and river flow data were obtained from Iringa Rural District and Rufiji Basin Water Offices (RBWO) based in Iringa municipality. Monthly rainfall and Lyandembera River flow data from 1997 to 2014 were collected at Kalenga and Ilongo stations, respectively. These data were used to investigate whether there is a relationship between the trend of rainfall and river flow in Lyandembera River.

Data analysis

Qualitative data were produced in an outline form to perform content analysis after organizing and coding into categories. Quantitative data were analyzed using Statistical Package for Social Sciences (SPSS) program (version 20).

Cross tabulation was used to compare different parameters from the two villages during data analysis. Then, information from SPSS was presented by graphs using Microsoft Excel software. Furthermore, the annual trend of rainfall and river flow data were analyzed by using Mann–Kendall's statistical test and linear trend analysis, and presented graphically using Microsoft Excel.

RESULTS AND DISCUSSION

The trend of rainfall and river flow

The study findings (Figure 2) on the mean annual rainfall and water flow indicate insignificant decreasing trends expressed by R^2 values of below 0.5. The decline in rainfall is higher by 39% of the observed variance ($R^2 = 0.390$) than that of the water flow (0.1%) ($R^2 = 0.001$). Similar declining trends on rainfall and river flow have been proved by Mann–Kendall's test. Even though both methods indicated declining trends in rainfall and river water flow, a slight observation was noted on rainfall significant levels, whereby the Mann–Kendall test indicates significant decline ($P = 0.000$) while linear trend analysis indicates insignificant decline ($R^2 = 0.390$). In Figure 2, one can observe marked deviations (rise and fall) in mean annual rainfall and water flow, implying the existence of year-to-year rainfall variability. The highest rainfall amount was observed in 2004/05 (220 mm) and the lowest was observed in 2014/15 (70 mm). Moreover, the highest water flow amount was observed in 1998/99 (484 m^3/s) and the lowest was observed in 1999 (12 m^3/s).

Insignificant decreasing trend of water flow influenced local perceptions on the trend of the river. In the household questionnaire, 68% and 70% of the respondents in Lumuli and Ifunda villages, respectively, reported that Lyandembera River flow used for traditional irrigation has been declining in the past 30 years (Figure 3).

The decline of river flow has negative impacts on crop production, especially on the *vinyungu* system in the study area as reported by 69 and 87% of the respondents in Lumuli and Ifunda villages, respectively, in the household survey. This could also have an impact on crop production in other areas that depend on water from the river for irrigation. It has been projected that key irrigation areas in Tanzania will face a decrease in rainfall as well as an increase in temperature that will increase evaporation of surface water resulting in water shortages for irrigation (TACRP 2014). Furthermore, URT (2012) showed that reduced amount and changed rainfall seasons have a negative implication on some perennial rivers such as the Great Ruaha in Iringa region.

Results of mean monthly rainfall and water flow, in Figure 4, indicate significant decreasing trends in water

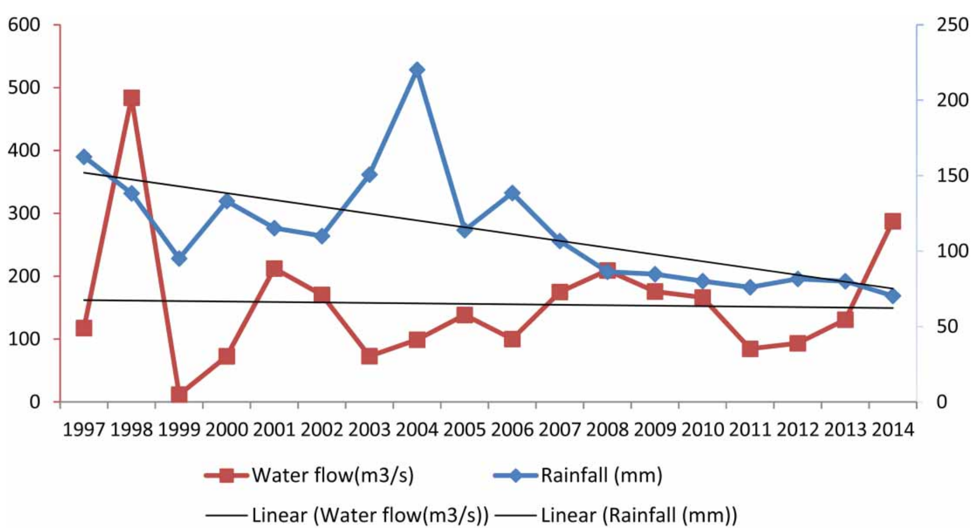

Figure 2 | Annual mean flow of Lyandembera River (m^3/s) and rainfall from 1997–2014 recorded at Ilongo and Kalenga stations, respectively.

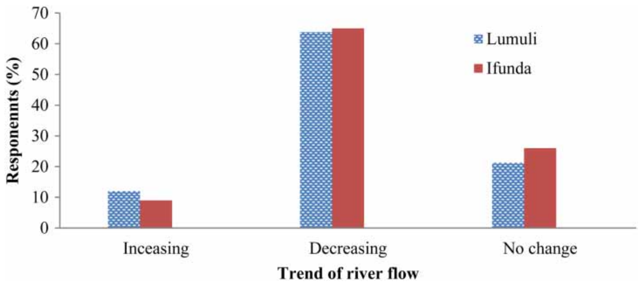

Figure 3 | Local people's perceptions on the trend of river flow in Lyandembera River. Source: field survey, 2015.

flow ($R^2 = 0.608$) with insignificant decreasing trends in monthly rainfall ($R^2 = 0.142$). The findings indicate that this area receives rainfall from November to May. A larger rainfall amount falls in May and the lowest falls in April. A slight difference is noted on water flow, where the river flows throughout with the minimum amount in some months. The highest amount was observed in March while October and November mark the lowest amount observed.

These findings are parallel with local people's perceptions revealed during the household questionnaire. It was reported that amount of rainfall, onset and end of the rainfall period in the study villages have changed compared to the past 30 years. In Lumuli village, 56% of the respondents stated that in the past 30 years rainfall used to start in November and end in May. This is contrary to recent years where it starts in December and ends in April. Likewise, in Ifunda village, 51% respondents reported that rainfall in the past used to start in November through to May. However, in recent years, 58% of the respondents' stated that it starts in November and ends in April. This has been directly observed in both villages during data collection done in April, a period for *nyahengi*, a local name of rains that is a sign of the end of the rainfall period. A study by Kassian (2012), in Mufindi District, Iringa region indicates the same type of rainfall (*nyahengi*) is a type of rainfall which used to be present in May up to July after the end of heavy rains. The rain was very crucial to the crops that take a long time to mature, planted in the middle of the rainy season and late planted crops (Kassian 2012).

Indicators of the decline in Lyandembera River flow based on local knowledge

Findings from the household questionnaire mentioned some indicators that show a declining pattern of river flow. In the household questionnaire, the majority of the respondents (69%) in Lumuli village revealed that drying of crops in *vinyungu* fields indicates that the water level in the river has been declining over the years. While in Ifunda village, 38% of respondents indicated that the decline of water in channels and wells used for irrigation in their plots in

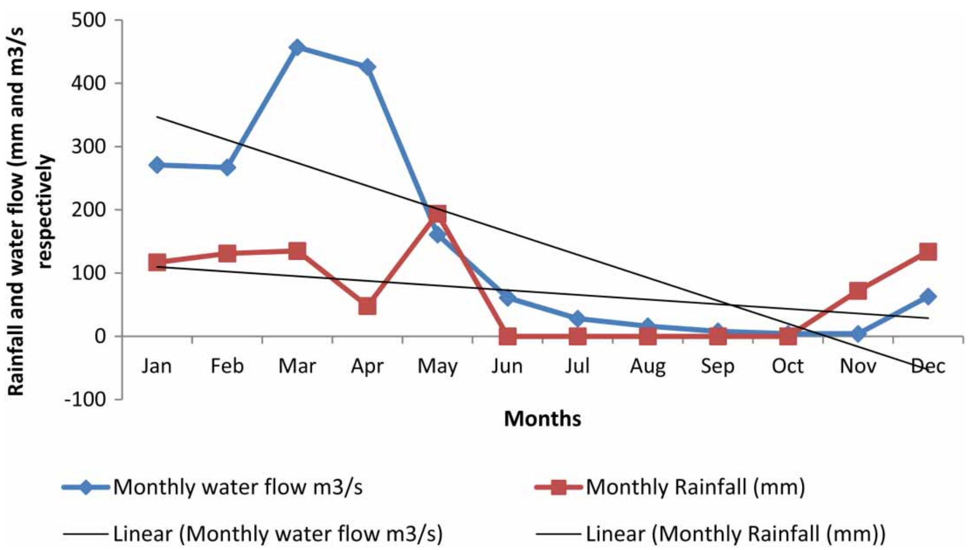

Figure 4 | Monthly average rainfall (mm) and Lyandembera River flow (m^3/s) at Kalenga and Ilongo stations, respectively (1997–2014).

recent years showed a declining pattern of river flow. The means of irrigation have influenced the respondents between the two villages to vary in their responses. Whereas in Lumuli village irrigation is conducted through water from the river, in Ifunda village irrigation water channels and wells are in use. Other indicators mentioned were visibility of objects such as stones in the river that were not visible in the past. Despite the fact that farmers associated stone visibility with the decline of river flow, scientifically the situation is a result of soil erosion within the river rather than the decline in river stage (Immoor 2006). This was also directly observed in Ifunda village (Figure 5(b)). Moreover, crossing of the river by foot during the rainy season which was not possible in the past was directly observed during data collection conducted during the rain period (Figure 5(a)).

During the FGD interview it was revealed that decline of river flow is caused by many factors, including declining rainfall amount and increased pressure on the utilization of water for irrigation in *vinyungu* fields due to increased

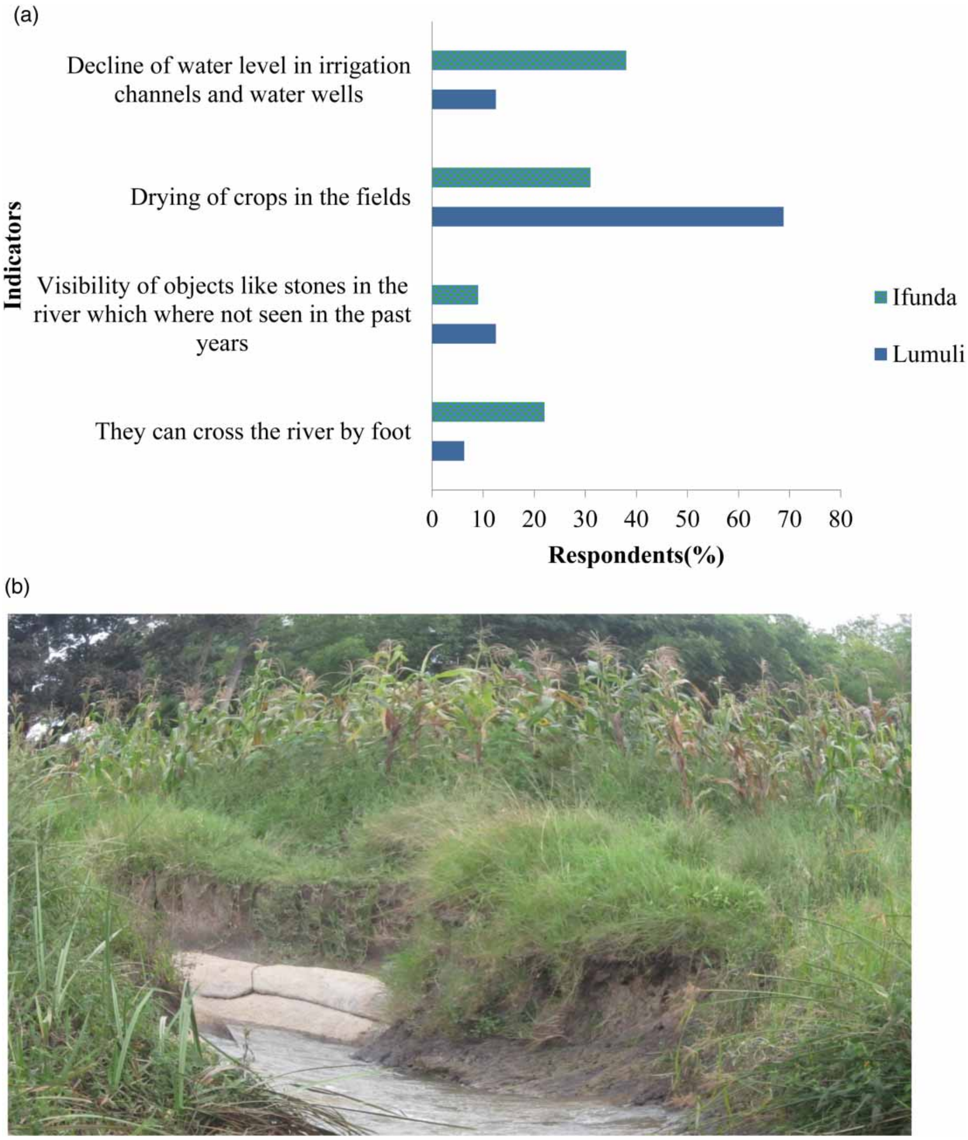

Figure 5 | (a) Indicators of declining Lyandembera River flow. (b) Visible stones in Lyandembera River, Ifunda village during the rainy season.

demand of *vinyungu* products. Environmental destruction including cutting down water-conserving trees such as *Syzygium cordatum*, locally known as *mivengi*, for *vinyungu* fields' expansion and increased demand for trees for charcoal making and firewood was also mentioned to be a source of river flow reduction. For instance, data analysis from satellite images in both wards show the decline in wetland and woodland areas, which probably include *mivengi*. Based on the study conducted by Kyando (2007), the decrease of river flow was a result of human activities such as irrigation taking place along the rivers, water catchments and in valley bottoms. Moreover, in the household questionnaire, about 72% and 44% respondents in Lumuli and Ifunda villages, respectively, revealed that the declining trend in Lyandembera River flow results from the decline of rainfall amount in recent years (Figure 6). This implies that the major factor is rainfall, based on the trend of river flow data, which corresponds to the trend of rainfall data in both study villages.

Adaptation strategies to water shortage in valley bottom fields and their relative costs

Findings from this study revealed that there is a tremendous decline in river flow used for *vinyungu* irrigation, resulting in a decline in crop productivity in the area. To cope with and maintain crop productivity, various practices have been employed and their costs were investigated.

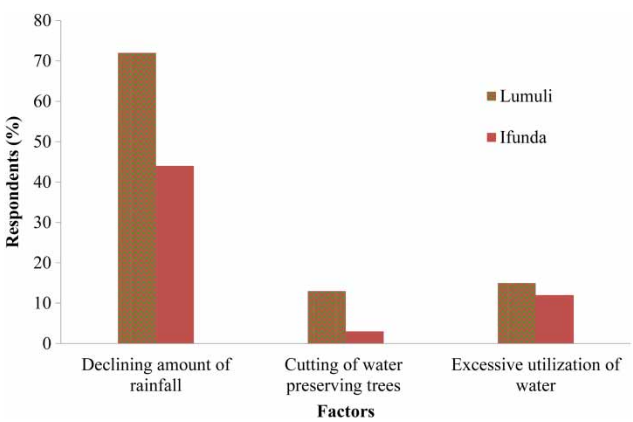

Figure 6 | Factors for the decline of Lyandembera River flow based on respondents' replies.

Irrigation and methods of irrigation

Findings from this study revealed that the majority (78% and 88% in Lumuli and Ifunda villages, respectively) of the respondents practice irrigation to maintain crop yields. According to Kassian (2012), irrigation is used in other areas within Iringa region, such as Mufindi district, to maintain crop yields in the changing climate. Irrigation is conducted mainly in the dry season using water from Lyandembera River via various methods, including dip wells, shallow canals diverted from the river, water pumps, and buckets. Household survey results revealed that the major source of water for irrigation in both villages is excavated shallow wells within the fields (Figure 7). It was reported that during water shortage farmers increase the depth of wells so as to get sufficient water for irrigation. Others divert water from the river using shallow canals to their fields, especially in Ifunda village, while other farmers increase the use of water by fetching it directly from the river. The same methods of irrigation are used in Kilolo District, Iringa region, Tanzania (Kyando 2007). Furthermore, the same method is reported to be practiced in the northern state of Himachal Paradesh in India to provide sufficient water, and farmers were reported to produce good quality crop yields (Gover *et al.* 2013).

Analysis from the household questionnaire showed that during the dry season about 29% of the respondents in Lumuli village spend 3–5 USD for irrigation per day per acre while in Ifunda village about 26% spend 16–18 USD for irrigation (Figure 8). This implies that in Ifunda village the cost of irrigation is higher than Lumuli village due to higher market opportunities for agricultural products within and outside the village. This increases the cost of production as high capital is used in irrigation to maintain marketable crop yields.

Major environmental problems associated with adaptation strategies

Findings from the study revealed that there are various environmental problems associated with the *vinyungu* farming system, as summarized in Figure 9. These problems include the decline of water in the fields. This was the first problem mentioned in association with increased utilization

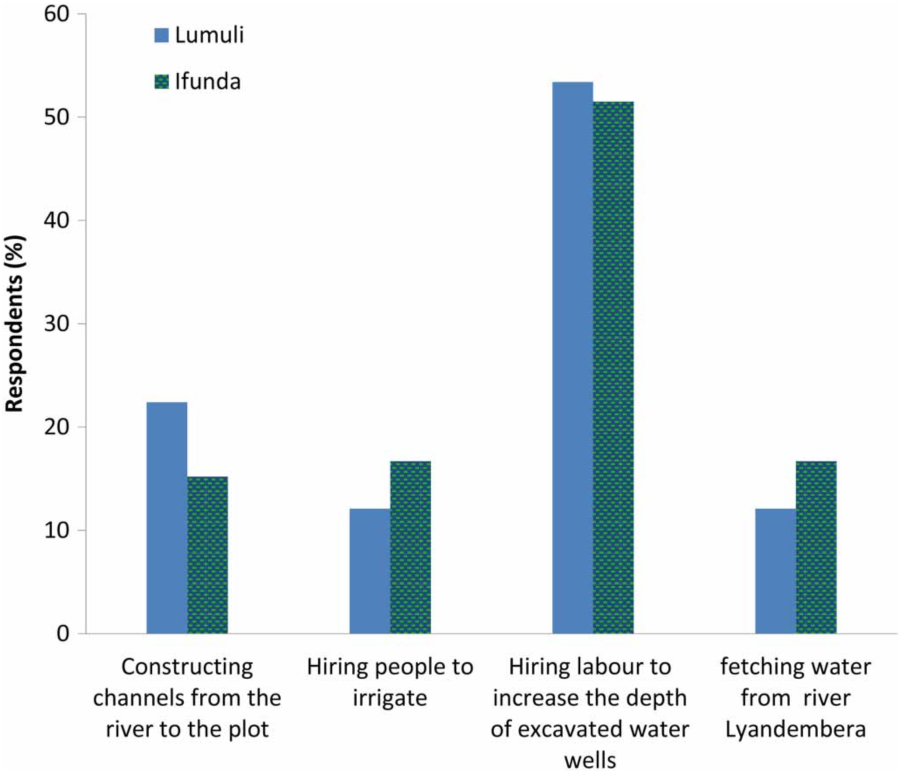

Figure 7 | Source of water for irrigation and methods used based on respondents' replies.

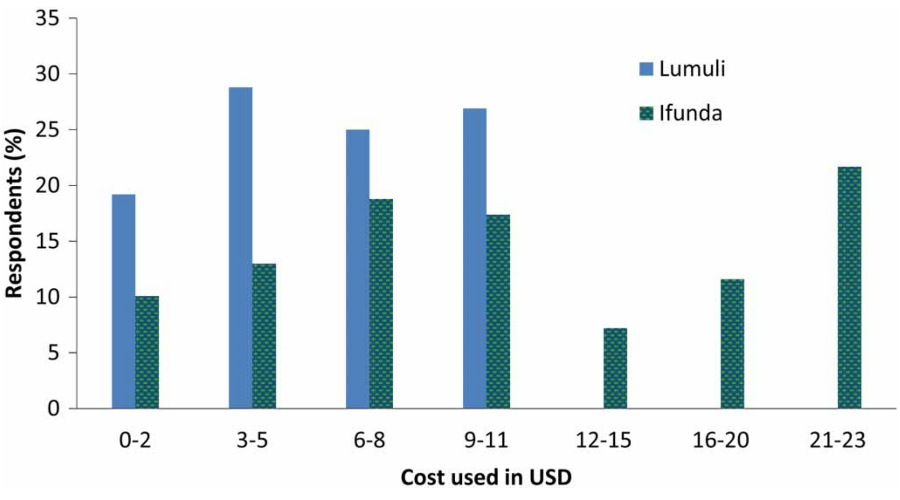

Figure 8 | Relative cost incurred in employing intensive irrigation based on respondents' responses.

of water for irrigation reported by 48% and 55% of the respondents in Lumuli and Ifunda village, respectively. The problem was associated with the decline of rainfall and over-utilization of water for irrigation through increasing the depth of excavated water wells in the fields. This could result in lowering the water table.

River diversion was reported by one of the key informants to cause water shortage to the downstream farmers

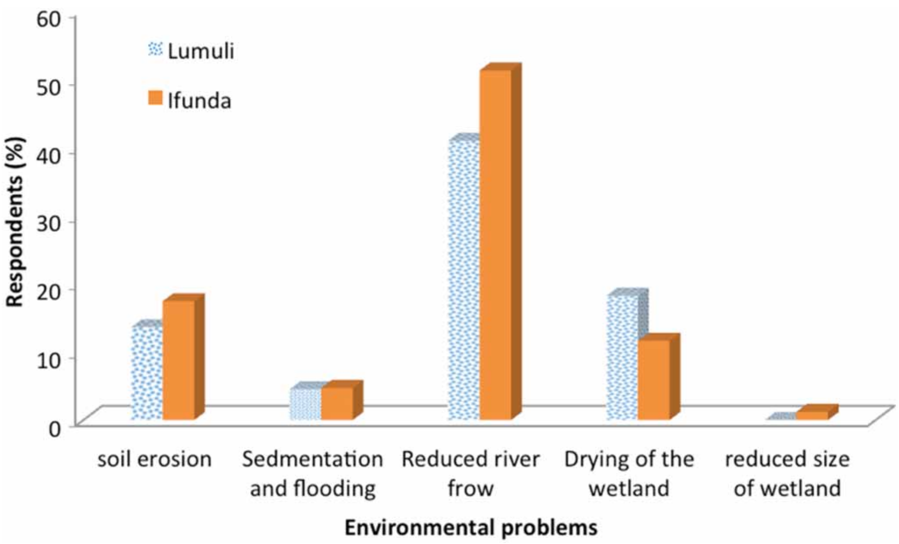

Figure 9 | Major environmental problems and areas associated with *vinyungu* farming practices based on respondents' replies.

in Lumuli village. In addition, fetching water direct from the river has been reported to cause destruction of natural vegetation and hence soil erosion in riverbanks. This could be exemplified by the visibility of stones in Ifunda village which local people associate with the decline of river flow (Figure 5(b)).

Reduced size and drying of wetlands was the second problem mentioned in the household questionnaire, in Lumuli village by 37% and 32% of the respondents in Ifunda. This also has been revealed in land-use/cover change analysis from satellite images in both wards. Images showed a decline of wetlands from 57.673 km^2 to 42.445 km^2 in Ifunda village and from 51.679 km^2 to 39.445 km^2 in Lumuli village from 1984 to 2014 (Table 1). This may be due to the fact that Lumuli village is located near wetlands surrounding the village. The *vinyungu* farming system in the village has a direct impact on wetlands by reducing them at the expense of expansion of the farming system. According to Magembe (2007) and Munishi *et al.* (2011), availability of moisture throughout the year in the changing climate forces farmers to expand cultivated areas.

Soil erosion was another problem mentioned by 26% of respondents in Ifunda village. This type of erosion is more pronounced on riverbanks (Figure 10). The problem was associated with *vinyungu* farming practiced in restricted areas, such as those within 60 m of the riverbank. At interview with one of the key informants at the village level, it was revealed that despite the presence of by-laws, villagers

Table 1 | Statistics of the rate of land use change in the study area

	IFUNDA ward				LUMULI ward			
	1984		2014		1984		2014	
Land use	(sq. km)	%	(sq. km)	%	(sq. km)	%	(sq. km)	%
Built-up	19.44	6.5	48.45	14.8	17.31	8.5	41.75	18.3
Bush-land	95.03	27.8	39.33	12.0	50.02	17.6	31.34	13.8
Reservoirs	0.17	0.1	1.86	0.6	1.41	0.6	1.86	0.8
Subsistence farming	93.17	28.4	164.04	50.0	98.29	43.1	104.19	45.7
Wetland	57.67	17.6	42.45	12.9	51.68	22.7	39.45	17.3
Woodland	68.26	19.6	31.65	9.7	19.08	7.5	9.31	4.1

Figure 10 | Eroded Lyandembera Riverbank in Ifunda village. Note the maize field in the background.

never abide by them. This probably is a result of few areas being suitable for *vinyungu* farming and poor enforcement of by-laws by village leaders. Expansion of *vinyungu* fields is done without considering the environment, which supports the fields. In Lumuli village, soil erosion, especially in their fields, was also mentioned by about 14% of the respondents as being associated with the *vinyungu* farming system. A study by Majule & Mwalyosi (2005) in Lushoto District has shown that farming practices along water sources threaten the *vinyungu* system through accelerated soil erosion on riverbanks. Furthermore, soil erosion was reported to be a major concern for the sustainability and productivity of the farming system in Rufiji basin (Majule & Mwalyosi 2005).

River sedimentation and *vinyungu* fields flooding were among the problems reported by a minority (5%) of the respondents in both study villages. These problems were reported to occur during heavy rainfall periods, which are accompanied by the destruction of *vinyungu*. Villagers in Lumuli reported that the problem was more pronounced in Lumuli village probably because of farming practices in wetlands. Wetlands act as a sponge to store water. This might further be due to the location of *vinyungu* in the lower stream in Lumuli village relative to Ifunda village. As a result, some of the farmers in Lumuli village abandoned the *vinyungu* system. Abandoned fields have positive effects on the environment as they increase wetlands. Similarly, Kangalawe *et al.* (2011) and Kassian (2012) have reported these problems to be prevalent in Mafinga District, Iringa region.

Generally, irrigation methods used have implications for the environment, as the practice may result in competition for water usage for different purposes such as domestic use. It may also result in the destruction of other living things such as wetland vegetation that depends on water for its survival.

Efforts employed to overcome environmental impacts

There are some efforts which are in place at the village level to overcome the environmental impacts of the *vinyungu* system in the study villages. These include restriction of cultivation near water sources and within 60 m from valley bottoms and river sources (URT 2004) and cutting water-conserving trees such as *S. cordatum* locally known as *mivengi.* This was reported during the FGD in both villages. Studies conducted by Kassian (2012) in Mufindi District and Kangalawe (2010) in Njombe region show that trees such as *S. cordatum*, *'misombesombe'*, *'mivelevele'*, *'misusuriana'* and *'midzobwe'* are used as water-conserving trees and some of them are planted in wetland areas. However, in Kilolo District, Kyando (2007) reported that seminars facilitated by the World Wide Fund for conservation of nature (WWF) in association with the staff from RBWO are conducted to train farmers in proper ways of conserving the environment including valley bottoms.

CONCLUSION AND RECOMMENDATIONS

Scientific evidence from this study is aligned with local perceptions that climate change in terms of rainfall decrease has implications on the trend of river flow. The trend of the river flow corresponds to the trend of rainfall which shows a slight declining pattern in the last 18 years. This has an impact on crop production in *vinyungu* fields located along the Lyandembera River, which depend on water from the river for irrigation. In maintaining crop productivity and soil moisture, various methods reported to be employed include increasing the depth of water wells in the fields, diverting the river through water channels to the fields, and increasing the use of water from the river. These affect river flow. Therefore, this study recommends that central and local government should put more efforts into enforcing laws and by-laws that restrict any human activities such as agriculture to be conducted on wetland and within

60 m from the river and around water sources. Furthermore, this paper recommends that more research should be conducted on proper water management and irrigation methods for sustainable river flow for both agriculture production and environmental management for different farmer typologies.

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