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Farmers' perception on climate change, soil erosion and adaptation strategies in small rural communities of Mali: case study of the rural municipality of Méguétan

Percepción de los agricultores sobre el cambio climático, la erosión del suelo y las estrategias de adaptación en las pequeñas comunidades rurales de Mali: estudio de caso del municipio rural de Méguétan

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Abstract

The impacts of climate change and soil erosion are significantly affecting agriculture in non-developed countries. In Mali, a country located in Western Africa, there is a drastic reduction in available fertile arable lands and water scarcity, which is damaging rural communities and affecting the development of vital infrastructures, consequently, decreasing people's incomes. There is a lack of information about the perception of these challenges among the small rural communities and the possible adaptation strategies can be applied. Therefore, the main aim of this study was to determine local farmer perceptions of climate change, soil erosion, and adaptation strategies conducting a survey among 200 farmers in 10 villages within the rural municipality of Méguétan, serving as a representative study case. Our results showed that farmers are aware of the challenges related to climate change and soil erosion and are willing to adopt some measures but conditioned by a range of traditional techniques. The most common strategies are: changing the sowing calendar, diversifying crops, using resistant varieties, having an alternative income, and following weather forecasts on the radio. Stone rows remain the most widely adopted technique to reduce soil erosion, with a knowledge rate of 88% and an application about 29%. The study also highlighted the increasing vulnerability of farmers to climate change and soil erosion due to insufficient material and financial resources. We conclude policies should pay attention to services and partners that invest more funds in technical assistance to strengthen adaptation strategies and teach the population, considering nature-based solutions.

Keywords: climate change; soil degradation; land management; regional studies; adaptation strategies; Méguétan.

Resumen

Los efectos del cambio climático y la erosión del suelo están afectando considerablemente a la agricultura de los países no desarrollados. En Mali, país situado en África Occidental, se está produciendo una drástica reducción de las tierras cultivables fértiles disponibles y escasez de agua, lo que está perjudicando a las comunidades rurales y afectando al desarrollo de infraestructuras vitales, disminuyendo en consecuencia los ingresos de la población. Existe una falta de información sobre la percepción de estos retos entre las pequeñas comunidades rurales y las posibles estrategias de adaptación que se pueden aplicar. Por lo tanto, el objetivo principal de este estudio era determinar las percepciones de los agricultores locales sobre el cambio climático, la erosión del suelo y las estrategias de adaptación realizando una encuesta entre 200 agricultores de 10 aldeas del municipio rural de Méguétan, que sirve como caso de estudio representativo. Nuestros resultados mostraron que los agricultores son conscientes de los retos relacionados con el cambio climático y la erosión del suelo y están dispuestos a adoptar algunas medidas, pero condicionadas por una serie de técnicas tradicionales. Las estrategias más comunes son: cambiar el calendario de siembra, diversificar los cultivos, utilizar variedades resistentes, disponer de ingresos alternativos y seguir las previsiones meteorológicas en la radio. Los terraplenes de piedra siguen siendo la técnica más adoptada para reducir la erosión del suelo, con un índice de conocimiento del 88% y una aplicación en torno al 29%. El estudio también puso de manifiesto la creciente vulnerabilidad de los agricultores al cambio climático y a la erosión del suelo debido a la insuficiencia de recursos materiales y financieros. Concluimos que las políticas deberían prestar atención a los servicios y socios que invierten más fondos en asistencia técnica para reforzar las estrategias de adaptación y enseñar a la población, teniendo en cuenta soluciones basadas en la naturaleza.

Palabras clave: cambio climático; degradación del suelo; gestión de la tierra; estudios regionales; estrategias de adaptación; Méguétan.

1. Introduction

During his interview on TV5monde in September 2022, Professor Youba Sokona, the Vice-Chairman of the Intergovernmental Panel on Climate Change (IPCC), emphasized that the African continent remains highly vulnerable to global warming (“L’Afrique et le changement climatique,” 2021). Rural inhabitants in Africa between the ages of thirty and forty are particularly vulnerable because they are already experiencing the effects of climate change firsthand, such as the spread of arid zones, desertification, heat waves, floods, and more frequent tropical storms (“L’Afrique et le changement climatique,” 2021).

Mali, like all countries in West Africa, is no exception to these challenges. Mali’s economy is predominantly reliant on the primary sector, with agriculture contributing to over 45% of its Gross Domestic Product and supporting 80% of the population´s livelihoods (Food and Agriculture Organization of the United Nations [FAO], 2017; Ministère de l’Environnement de l’Assainissement et du Développement Durable [MEADD], 2020). However, the country faces significant climate-related risks as it heavily relies on agricultural practices carried out on poor and fragile soils (Ministère de l’Agriculture, 2013; Coulibaly & Sissoko, 2021). Approximately 80% of the population is directly or indirectly dependent on agricultural activities. Consequently, the agricultural sector plays a vital role in driving economic growth and ensuring food security in Mali (Ministère de l’Agriculture, 2013), accounting for 3.6% of the average growth rate (Weisz et al., 2014). Even in urban areas, a substantial proportion of the population is engaged in agriculture (Bélières et al., 2014).

The agricultural sector is encountering numerous difficulties, including climatic factors linked to highly variable weather conditions, political instability (such as unfavorable positions in international trade, etc.) and socio-economic challenges (like demographic pressure, intense urban sprawl, soil sealing, etc.) (Sangaré, 2018). Climate change is expected to have a range of adverse effects on agriculture, and these impacts are projected to increase significantly in the near future, leading to a rapid escalation of pressures on agricultural systems and ecosystem services (Bocci & Smanis, 2019). For instance, according to the United Nations Environment Programme (UNEP), Mali could witness a 30% drop in cereal yields by 2040 (Kwasi et al., 2019). The projected 2°C rise in temperature above pre-industrial levels is highly likely to reduce millet, sorghum, (two of the most crucial crops for food security) by a quarter by 2080 (Kwasi et al., 2019).

In Mali, soil degradation due to erosion (which varies in space and time (Mounirou et al., 2022)) has become significant and worrying as in the whole of the Sudano-Sahelian zone of West Africa (Touré et al., 2020). It is prevalent and leads to an enduring environmental and humanitarian crisis. Agricultural land is subjected to immense degradation and the loss of important soil nutrients due to soil erosion (Bengaly, 2009; Sanogo et al., 2023). The highest soil erosion rates are registered in agricultural fields, resulting in a reduction in agricultural land and a loss of nutrients that are useful for plant growth (Sanogo et al., 2023). The growing demand for food production coupled with the lack of knowledge about the limiting attributes of soils induce soil degradation (Kaya et al., 2007). The report on the Economic, Social and Cultural Development Programme from the Ministry of Local and Regional Authorities indicates that the rural municipality of Méguétan is suffering from severe water erosion (Ministère des collectivités territoriales, 2021).

Numerous studies in the scientific literature have examined farmers' perceptions of climate change and adaptation strategies, not only at national level but also at regionally in countries like Nigeria, Namibia, Benin, Ethiopia, Burkina Faso, Ivory Coast, Niger, and at international level in other countries such as France (Albert et al., 2022), China (Zhong et al., 2022), India (Reddy et al., 2022; Datta et al., 2022; Meena et al., 2019), Mexico (Fierros-González & Lopez-Feldman, 2021), Germany (Eggers et al., 2015), Spain (Cerdà & Rodrigo-Comino, 2021), Bangladesh (Ferdushi et al., 2019), Peru (Landaverde et al., 2022), etc. However, in Mali, the focus of studies on farmers' perceptions has been predominantly on sorghum productivity in the Soudanian and Sahelian zones (Traoré et al., 2021), in the urban municipality of Niono (Segou Region) (Reddy et al., 2022), the southern regions (Soumaoro et al., 2022), resources and production systems in the Yélimané district (Penda et al., 2020), livestock farming and adaptation strategies in the rural municipality of Tioribougou (Sanogo et al., 2022) and farming strategies in the municipality of Guihoyo (Kolokani district) (Coulibaly et al., 2020). Yet, limited research has combined the perceptions of small rural communities regarding climate change, soil erosion and possible adaptation strategies. This gap is particularly worrying, given that soil erosion is a serious threat to sustainable development (Gao et al., 2018, 2021) and significantly impacts agriculture due to loss of soil, nutrients, and organic carbon (Bezak et al., 2021; Rodrigo-Comino et al., 2020).

To address this gap, a study was conducted in the rural municipality of Méguétan, which represents a representative rural area within Mali characterized by numerous small rural communities. The primary goal of this study was to contribute to a better understanding of two critical issues that are adversely affecting crop yields and threatening food security: climate change and soil erosion. To achieve this objective, a survey was carried out among 200 farmers in 10 villages within the mentioned rural municipality.

2. Methodology

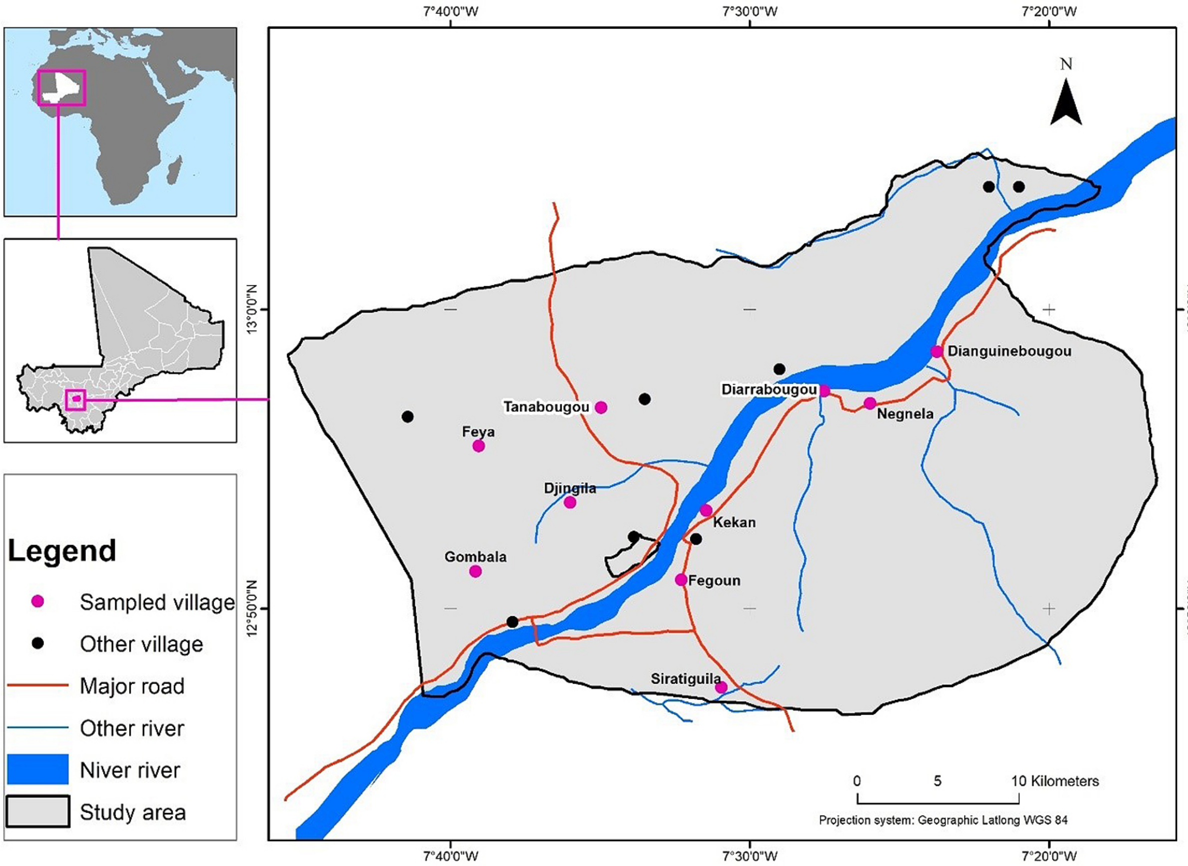
2.1. Study area

Located on both sides of the urban municipality of Koulikoro, Méguétan is encompassed by a belt of hills and stretches along the Niger River, flowing through it from south to north. The rural municipality of Méguétan experiences a Sudanese-Sahelian climate (Coulibaly, 2022), characterized by three distinct seasons: i) the hot dry season lasts from February to June, marked by winds throughout the day and night. The period is characterized by relatively low humidity and high evapotranspiration; ii) the cool dry season occurs from November to February, with relatively low wind and temperature; and, iii) the wet, warm season from June to October, being the most favorable period for vegetation growth. Throughout the year, the temperature in Méguétan varies between 17 and 45°C, while the average annual rainfall ranges from 700 to 900 mm.

Méguétan is characterized by hydromorphic soils. These have an average depth of about 125 cm at foot slopes and are considered heavy and challenging to work by farmers. Approximately, 41% of Méguétan farmers cultivate this soil. The main crops grown in these soils are sorghum, maize and millet (Coulibaly, 2022). They are also affected by streams or temporary channels, which can be transformed into rills and ephemeral gullies after strong rainfall events. These soils also experience gleyfication in very deep horizons (140 cm) located in the temporary flood zone of the swamps. They cover around 10.3% of Méguétan's are and are used for rice cultivation. Tropical ferruginous soils can be found on spreading pediments with a depth of 140 cm. They account for a significant portion of Méguétan's land and are utilized for cultivating sorghum, cotton, millet, and maize. Soils with high gravel content and crust blocks are less prevalent in the area, constituting only 16.2% of Méguétan's surface. They have a depth of less than 50 cm and are not suitable for mechanization using animal traction. The main crops grown in these soils include cowpeas, sorghum, millet, and groundnuts. Finally, leptosols located in slightly sloping areas have a shallow crust of about 25 cm make up only 2.3% of Méguétan's soils. They are primarily used for rice cultivation (International Union of Soil Sciences- World Reference Base for Soil Resources [USS-WRB], 2022).

In Méguétan, soil management is primarily focused on both food and cash crop, although there are still some underexploited plains. Various food crops cultivated in the region include *Zea mays* (maize), *Pennisetum glaucum* (millet), *Sorghum bicolor* (sorghum), *Oryza sativa* (rice), *Vigna unguculata* (cowpea) and *Vignasubterraneana* (wandzou). Cash crops, on the other hand, consist of *Gossypium spp.* (cotton), *Rachis hypogaea* (groundnut) and *Sesamum indicum* (sesame). Also, some fruit trees can be found such as *Vitellaria paradoxa* (shea), *Parkia biglobosa* (néré), *Khaya senegalensis* (baobab), *Coccoloba uvifera* (grape) as well as plantations such as *Magifera indica* (mango), orange trees, *Psidium guajava* (guava), *Citrus limon* (lemon) and *Anacardium occidentale* (cashew). However, agricultural sector in the region faces several challenges including: i) non-degradation of plastic waste in nature; ii) loss of land due to erosion and soil poverty; and, iii) the scarcity and irregular distribution of rainfall. To address these challenges and enhance agricultural productivity, farmers in Méguétan use a combination of agricultural inputs. These inputs include chemical fertilizers like diammonium phosphate, urea, cereal complex, and cotton complex, as well as organic fertilizers like manure and other organic materials (Coulibaly, 2022). By utilizing a mix of these inputs, farmers aim to improve soil fertility and enhance crop yields in the region.

Figure 1. Location of the rural municipality of Méguétan



Own elaboration

2.2. Field survey and sampling and data collection

It is well-known that local rural communities in many parts around the world possess valuable knowledge about natural resources, especially soil management (FAO, 2017; Warren, 1992). Integrating this local knowledge with that conventional one produced by academic institutions can lead to a better understanding and appreciation of natural resources (Diallo & Keita, 1995). The data presented in this study were collected through direct observation in various fields and complemented by interviews and ten focus group discussions in 10 different villages within the Méguétan municipality (where 92% of the population lives exclusively from agricultural production (Keita et al., 2023)). Moreover, a total of four moderators have been involved in the interview process. Field observations in each village focused on identifying practices aimed at reducing soil erosion and to efficiently manage the water resources. For the focus group discussions, participants were randomly selected from each village to provide insights into their adaptation strategies and the use of anti-erosion technologies. The questionnaire and interview guide for the focus groups were developed after preliminary analysis of the field. Key terms such as climate change, erosion, soil management, management techniques, style and agricultural productivity were discussed during these sessions. Additionally, field observations were made after each focus group discussion. Surveys were conducted among 200 farmers, all aged 40 years or over, in the middle of the 2022 agricultural season. The aim was to understand rural local knowledge about climate change, adaptation strategies, soil erosion and techniques to combat it. The selection of head farmers was done systematically based on the list provided by the farmer's leaders of the selected villages. These individuals, identified with the support of village chiefs, were experienced producers with significant knowledge of their environment. The survey actively involved women, with almost 25% of the respondents being women engaged in agriculture. To validate questionnaires, a simulation was carried out on a sample of four farmers around Katibougou village. The form was improved and validated based on the results of this simulation (find questionnaire in the appendix). Table 1 shows the distribution of the population by gender in the involved villages. These data were provided by the economic, sectoral, and cultural development programs.

Table 1. Population distribution by village involved in survey

Villages	Male	Women	Total
Dianguinebougou	1,177	1,144	2,321
Diarrabougou	707	687	1,394
Djindjila	149	145	294
Feya	1,040	1,011	2,051
Gombala	332	323	655
Kekan	1,139	1,108	2,247
Negnela	691	672	1,363
Siratiguila	241	234	475
Tanabougou	173	168	341
Tonga	265	257	522
Total	5,912	5,751	11,663

Source: Parallel and Distributed Scientific and Engineering Computing (PDSEC), 2020

2.3. Statistical analysis

The responses of the rural inhabitants were analysed using SPSS software version 21.0 (IBM, USA). Data collected from the respondents were carefully reviewed and edited to correct any missing information on the questionnaires, ensuring accurate results. Excel software was utilized for data capture, codification and processing. A database was established to organize the information collected during the survey. For quantitative secondary data, the analysis was conducted using flattening techniques. On the other hand, for qualitative data, a synthesis matrix was developed and employed to better structure the information. Later, the data were coded with the assistance of SPSS v21.0. (IBM). The coding of the data facilitated the categorization of the respondents' views and enabled appropriate data analysis. Statistical analyses, such as averages and frequencies, were utilized to analyze the collected data. Descriptive statistics, including frequency distribution, percentage, mean, and standard deviation, were used to determine the frequency and percentage.

To compare the farmers' perception of climate change with actual conditions, corrected rainfall and temperature data series for Katibougou station (12°56' N, 7°37' W, 326 m a.s.l.) were used. These data were derived from a fusion of gauge and satellite data. Non-parametric trend analysis using the Mann-Kendall test in R software was performed to assess rainfall trends over the last 38 years (from 1983 to 2021). The Mann-Kendall test examines increasing or decreasing trends in a monotonic series based on two hypotheses: i) the null hypothesis, where there is no trend in the time series, and ii) the alternative hypothesis, where there is either an increasing or decreasing trend in the time series. An advantage of the Mann-Kendall test is that it is non-parametric, meaning it does not require the series to be normally distributed or linear (Yue & Wang, 2002).

3. Results

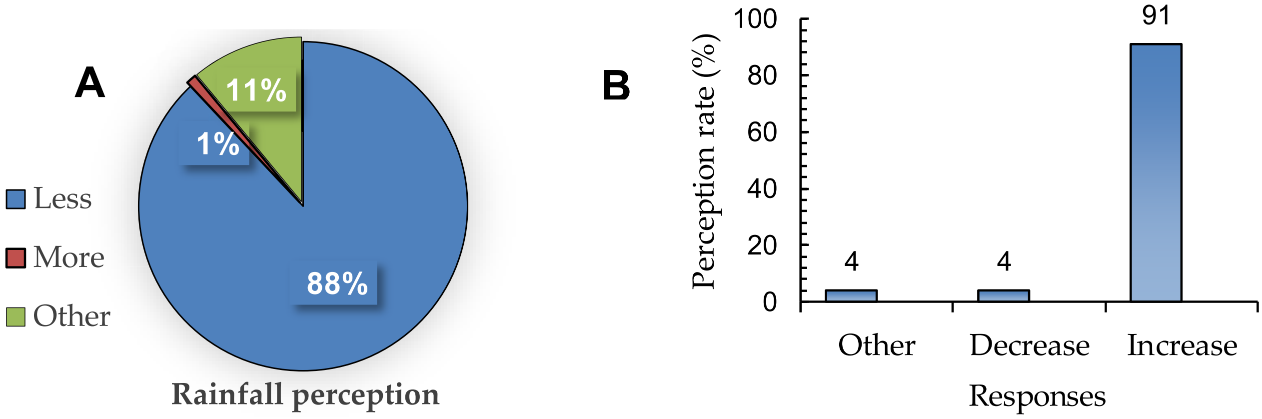
3.1. Impacts of climate change

The findings of the study reveal that a significant proportion of farmers, specifically 93% of those interviewed, are already aware of the effects of climate change. This awareness is understandable as agricultural campaigns have become more challenging, and the population has been actively following radio news, which frequently covers information about climate change. These factors contribute to the alignment of the population's knowledge with the ongoing discourse on climate change.

3.2. Rainfall and temperature situation over the last 30 years

Figure 2A shows that nearly all the farmers interviewed (almost 100%) perceived changes in the rainfall trend in their respective areas over the last 30 years. These changes have been experienced not only in the intensity of the rains, but also in the length of the rainy season and the amount of rainfall. Many farmers specifically noted a significant decline in rainfall, especially during the 2020-2021 season. Although perceptions of rainfall patterns vary among farmers, the most common observation reported by 88% of the farmers is a decrease in annual rainfall amount. Figure 2B indicates that 91% of the farmers interviewed have observed an increase in temperature over the last thirty years. Only 4% of the farmers mentioned that they believed the temperature is getting cooler than before, and another 4% considered the temperature to be unchangeable. However, the consistent observation of an increase in temperature is already a cause for alarm for the majority of farmers.

Figure 2. Rainfall and temperature situation over the last 30 years



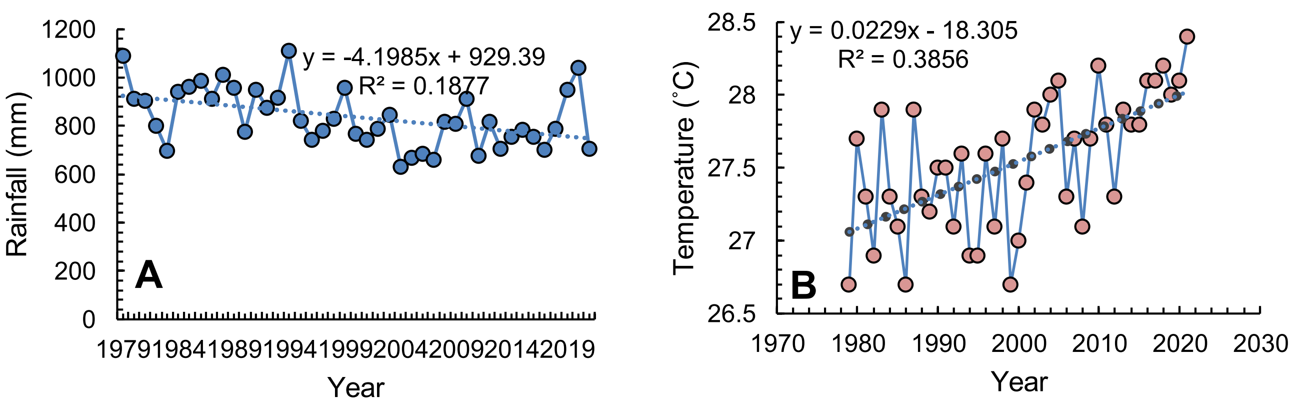
A. Rainfall perception by farmers; B. Temperature trend perception by farmers.

Own elaboration

In Figure 3A, the mean plot illustrates the actual data of rainfall variability over the last 30 years. The graph shows that precipitation is subject to significant variations from year to year. This observation aligns perfectly with the farmers' perception of change in the amount of rain that has been recorded in previous years. The variability in rainfall experienced by farmers is consistent with the actual data of rainfall variability shown in the mean plot.

The graph in figure 3B presents an estimate of the average annual temperature data from the Katibougou station. The dotted blue line represents the linear trend of temperature since 1979. Notably, the trend line slopes from left to right, indicating a positive trend in temperature. This trend suggests that the region is experiencing increasing temperatures over time, and it is getting hotter in the area.

Figure 3. Rainfall and temperature in Katibougou station



A. Total annual rainfall registered in the study area. B. Mean annual average temperatures in the study area.

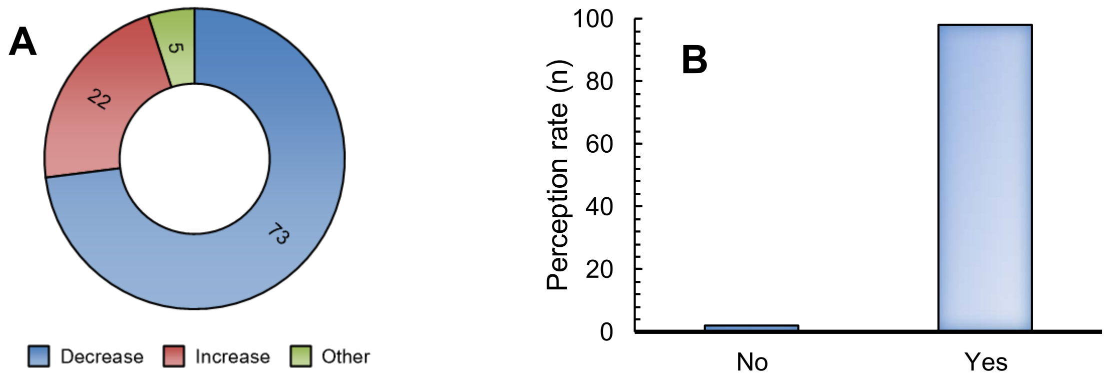
Own elaboration

3.3. Crops yield and soil erosion

The results presented in Figure 4A indicate that 73% of farmers confirmed a decline in crop yields, mainly millet, sorghum, maize, cotton, sesame, groundnuts, cowpea and vegetable crops (tomatoes, shallots, onions, cucumbers, lettuce, etc).

Additionally, the survey results in Figure 4B revealed that a significant majority of farmers (98%) in Méguétan are aware of soil erosion. They recognize the close link between soil erosion and agriculture, which ultimately leads to food insecurity. Among various types of erosion, water erosion was identified as the most destructive in the fields.

Figure 4. Evolution of crop yields over the last 30 years and soil erosion (A) and human perception (B)

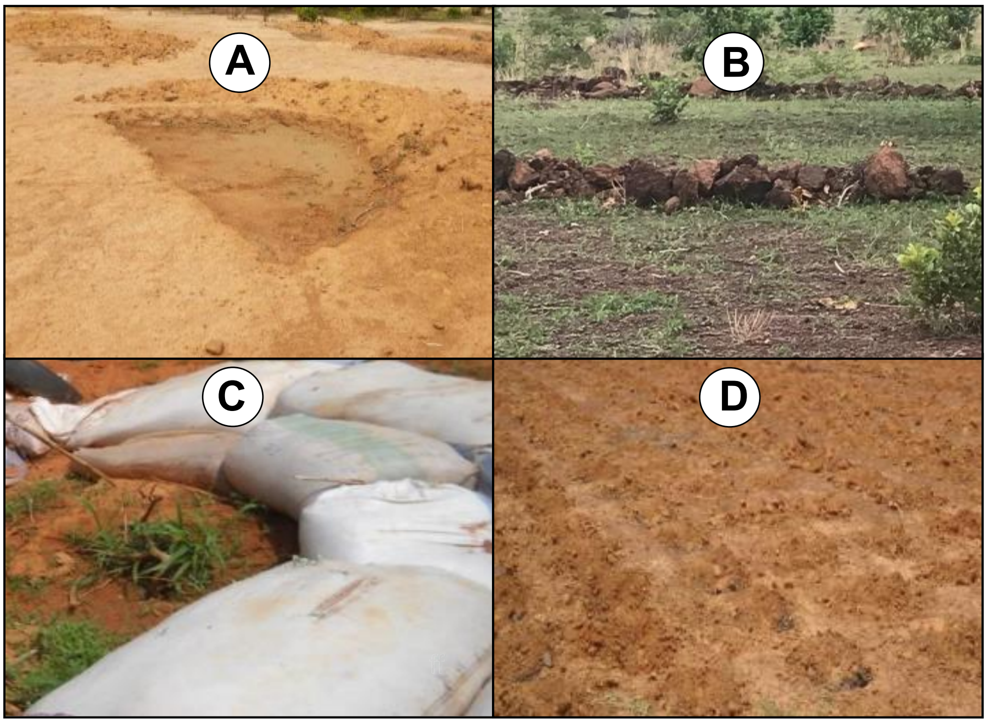


Own elaboration

3.4. Government contribution to the fight against soil erosion in cultivated areas and adaptation strategies

The government's contribution to addressing soil erosion in the municipality of Méguétan appears to be minimal, according to 87% of farmers surveyed. Many indigenous people report that the last major support projects aimed at combating soil erosion date back to the 1980s. These interventions involved implementing techniques such as stone rows, filtering dikes, grass strips, and others.

Figure 5. Some indigenous soil management techniques in Méguétan



A: halfmoon; B: stone rows; C: sand bags; D: Zaï.

Own elaboration

3.5. Field inventory of soil erosion reduction techniques

Based on the field inventory and information received from various sources such as World Overview of Conservation Approaches and Technologies technical services (hydraulics, rural engineering, agriculture, water and forests), NGOs, and farmers, several adaptation techniques and technologies have been identified in the municipality of Méguétan. These techniques are aimed at addressing soil erosion and water control. The inventory includes the following: i) eighty-eight fields with stone rows, covering an area of 29 hectares, located in Diarrabougou, Dianguinebougou, Falan, and Djindjila; ii) two vegetated stone rows, covering an area of 0.25 hectares; iii) a 1-hectare Zai field in Diarrabougou at Negnele; iv) a simple manual dike in Diarrabougou; v) three fields protected by sandbag barriers, covering a total area of 7 hectares; vi) a cyclopean concrete dam in Djindjila; vii) fields protected by tree planting; viii) a field of half-moon at Gombala; and, ix) six fields with hedgerows in Feya, Djindjila, Dianguinebougou, Diarrabougou, Negnele, and Kekan. The government should consider establishing programs that specifically target sustainable development and implement anti-erosion technologies. These techniques are widely used not only in the municipality of Méguétan but also throughout Mali. They are particularly prevalent in arid or semi-arid, Sudanian, and Sahelian regions where there is a significant amount of degraded land. These adaptation practices play a vital role in mitigating the impacts of soil erosion and enhancing water management in agricultural landscapes, contributing to sustainable land use and improving resilience to climate change in the region.

Table 2 provides the situation of water and soil conservation, defence and restoration techniques implemented in the rural municipality of Méguétan. With the exception of the Djindjila micro-dam, which seems to be a government initiative, almost all other structures listed are community-driven initiatives. These results indicate that many local initiatives have been taken and successfully implemented to implement water and soil conservation techniques and water control structures in the region. It is commendable to see the combined use of different types of development, such as agricultural, hydraulic, and forestry approaches, demonstrating a holistic and integrated approach to addressing soil erosion challenges. Furthermore, 48% of the population in Méguétan are engaged in activities other than farming. While this percentage is lower than the rate of people solely engaged in farming (52%), it is still significant and highlights the farmers' proactive approach.

3.6. Credit unions

All the respondents surveyed were aware of the credit unions available in the region, particularly the most active ones such as CAECE JIGISEME and Kafo JIGISEME, which are located in the urban municipality of Koulikoro. These credit unions play a crucial role in assisting farmers in accessing financial resources, enabling them to better prepare for the rainjy season and cope with the impacts of climate change (African Financial Alliance on Climate Change [AFAC], 2023). By providing financial services, these credit unions offer an alternative means of adaptation to the effects of climate change. Having financial resources available through credit unions allows farmers to invest in sustainable agricultural practices, acquire improved seeds and inputs, implement soil and water conservation measures, and diversify their income-generating activities.

3.7. Other sources of income

Diversifying income-generating activities is not only a strategy to compensate for the decrease in financial resources resulting from climate change and soil erosion but also a means to cope with the increasing expenses associated with agricultural production. According to the information obtained, fishing, animal husbandry, small-scale trade, and masonry work are among the main income-generating activities undertaken by farmers in addition to agriculture. Having multiple sources of income can provide financial security, opportunities for growth, flexibility, diversification, and personal satisfaction. These factors contribute to strengthening the resilience of farmers and their ability to withstand various challenges, including climate-related ones. In conclusion, the local initiatives to combat soil erosion, combined with the diversification of income-generating activities, demonstrate the proactive and adaptive approach of farmers in Méguétan. Such initiatives are vital in building resilience and sustaining livelihoods in the face of changing environmental conditions and economic challenges.

The diversification of income-generating activities is not only a strategy to compensate for the decrease in financial resources but also to cope with the increase in expenditure. According to the information obtained, fishing, livestock farming, petty trading, and masonry are the main income-generating activities after agriculture, with rates of 11%, 8%, 6%, and 3% of farmers practicing other activities.

Table 2. Inventory of water and soil conservation, defence and restoration techniques implemented in Méguétan

	Description	Location	Crops	Observations	
				Constraints mentioned	Proposed solutions
Stone rows	The stone rows are anti-erosion structures made up of blocks of rubble or stones laid one on top of the other	Djindjila, Feya, Diarrabougou, Dianguinebougou, Negnela, Fegoun, Tanabougou, Gombala, Kekan, Siratiguila	Millet, sorghum, maize, groundnuts, cowpea	Difficulty accessing, collecting, transporting and charging rubble around certain fields, labour.	Material and financial support for transporting the rubble and carrying out the work
Vegetated stone rows	Planted with *Anacardium occidentale* and *eucalyptus globulus* trees all along the stone lines				
Zaï	Zai is a farming technique for reclaiming/conserving and fertilising the soil, using planting material in the form of potted plants.	Negnele	Millet, sorghum, cowpea	Unavailability of organic matter and difficulty in transporting it to the fields; High demand for labour	Material and financial support; Producing organic manure
Half-moon	The half-moon is a compacted earth or stone structure in the shape of a semicircle, with openings perpendicular to the direction of water flow and arranged in a staggered pattern.	Gombala	Millet, sorghum, maize, groundnuts, cowpea	Requires annual maintenance work, Risk of degradation by trampling animals	Material and financial support for the implementation and annual monitoring of the project
Partitioned ridge	Agronomic method of sowing on permanent mounds (ridges) formed the previous year with the use of a ridger-weeder.	Tanabougou, Kekan, Negnela, Gombala	Millet, sorghum, maize	Insufficient equipment for mounding	Material and financial support to mechanise the construction of partitioned ridges
Simple manual dike	The simple manual bund is a structure built of compacted earth, generally in successive layers to make it impermeable. According to the survey data, this is a purely peasant initiative and is built by hand using muscular effort.	Diarrabougou	Millet, maize, rice	Very high labour costs; Damage to the rows after each winter season caused by heavy run-off.	Material and financial support to mechanise its construction, technical training support for monitoring and regular maintenance of the structure
Barriers in gullies	Dry stone dyke placed perpendicular to the course of the channel	Tanabougou	Maize, millet, cowpea	Collecting, charging and transporting stone.	Material and financial support for collecting, charging and transporting stones
Sandbags	This is a system of bags containing earth or sand to block run-off water, thereby combating soil erosion.	Feyan, Kekan, Fegoun,	Millet, sorghum, maize, cowpea	Insufficient implementation equipment	Material and financial support for the availability and filling of bags and the sand collection process
Planting trees and hedges, windbreaks	These are linear plantations of trees, shrubs or bushes in one or more rows, of one or more species, and generally planted perpendicular to the prevailing wind or the wind most harmful to the crops, villages or even infrastructure (roads, water points, schools, etc.) that they are intended to protect.	Fegoun, Siratigila, Kekan, Diarrabougou, Dianguinebougou, Negnela, Gombala, Djindjila, Tanabougou	Millet, sorghum, maize, sesame	Roaming animals destroying young tree plants, bush fires destroying trees, difficult access to nurseries.	Subsidize tree nurseries, change behavior, weed tree rights-of-way, tree plants Material and financial support to protect young trees until they develop
Cyclopean concrete dam	An anti-erosion measure involving the treatment and protection of banks, built across ravines perpendicular to the direction of water flow.	Djindjila	Rice, maize, cowpea	Lack of construction materials; Difficulty of access to materials	Material and financial support for access to materials and the execution of the dame

Own elaboration

4. Discussion

4.1. Climate change perception

Finding on climate change perception are consistent with those obtained in previous studies, which also demonstrated that climate change is widely perceived by local communities in Mali. For instance, Traore et al. (2021) observed that all farmers in the Sudano-Sahelian zone of Mali were aware of climate change (Traoré et al., 2021). Similarly, Sanogo et al. (2022) surveyed livestock farmers in the rural commune of Tioribougou and confirmed that they were experiencing climate change and had a good perception of its impacts (Sanogo et al., 2022). Another study conducted by Doumbia & Depieu (2013) among 144 rice producers also indicated that farmers clearly perceived the effects of climate change.

This observation aligns with findings from another study conducted in Tioribougou, where 95.11% of farers confirmed a change in the rainfall situation (Sanogo et al., 2022). Similarly, in Vea catchment, over 94% of the farmers believed that the amount of rainfall, its duration, intensity and the number of rainy days had decreased (Limantol et al., 2016).

Regarding the temperature situation, the statements made by the farmers align with the findings of another study conducted by Bambara and al. In their study of the socio-environmental consequences of climate change in Tougou and Donsin, they also reported considerable impact of temperature increase on various aspects. These impacts included the drying up of watercourses, the disappearance of low-lying areas, the lowering of the water table and the degradation of plant cover (Bambara et al., 2013). The concurrence between the farmers' observations and the findings of previous research highlights the urgency of addressing the issue of rising temperatures and its implications for the environment and agricultural practices in Mali. Such evidence reinforces the importance of implementing effective climate change mitigation and adaptation strategies to safeguard the livelihoods of rural communities and ensure sustainable agriculture in the face of a changing climate.

Furthermore, a recent study carried out in Mafele village (Traoré et al., 2023) also highlighted the interannual variability of rainfall in the region, dating back to the 1970s. This further confirms the existence of substantial year-to-year fluctuations in rainfall patterns in the area. The demonstrated variability in rainfall emphasizes the challenge that farmers face in planning and managing their agricultural activities (Negash et al., 2023). In their study on evapotranspiration and crop coefficient of sorghum (*Sorghum bicolor* L.) at Melkassa Farmland, Semi-Arid Area of Ethiopia, Negash et al. (2023), find in the weather characteristics that the total amount of rainfall recorded in 2018 was less than 24.2% of the rainfall amount recorded in 2017. It underlines the need for climate-resilient agricultural practices and adaptive strategies to cope with the uncertainties associated with changing rainfall patterns. Understanding and acknowledging the interannual variability of rainfall is crucial in formulating effective agricultural policies and programs to ensure sustainable food production and livelihoods in the region.

The average annual temperature data from the Katibougou station is consistent with the results of a study that assessed the change trends of daily temperature and precipitation extremes in Bamako and Ségou, Mali, spanning the period from 1961 to 2014. The study emphasized that climate change poses a threat of increased air temperatures and evapotranspiration in the region (Halimatou et al., 2017). Moreover, in a climate trend analysis of Mali conducted by Funk et al., it has been observed since 1975, temperatures have risen by over 0.8 °C across most parts of Mali, with typical warming rates exceeding 0.2 °C per decade (Funk et al., 2012).

4.2. Crop yield and soil erosion

The findings about the evolution of crop yields over the last 30 years align with the results obtained by the Planning and Statistics Unit of the Ministry in charge of Rural Development in 2022, which also emphasized changes in crop yields due to the damaging effects of climate change. The 2022 report indicated a decrease of 10.5% compared to 2020 (Keita, 2022). The consistency between the farmers' observations and the official data highlights the adverse impact of climate change on agricultural productivity and the implications for food security in the region.

Soil erosion perception aligns with the findings of Touré in the chapter entitled "Overview, trends, and factors in land degradation" (Touré, 2020). Moreover, the Ministry of the Environment, Sanitation, and Sustainable Development reported that Mali lost 489,200 hectares of agricultural land over a fifteen-year period (MEADD, 2020). This alarming data supports the farmers' concerns about soil erosion and its detrimental impact on agricultural land and food production in the region. These findings underscore the urgency of addressing soil erosion and implementing sustainable land management practices to safeguard agricultural productivity and food security in Mali. Climate change adaptation strategies and land conservation efforts are essential to mitigate the effects of soil erosion and ensure the resilience of agricultural systems in the face of ongoing environmental challenges.

At the national level, the government's agricultural policies have primarily focused on increasing domestic rice production, reforming the cotton sector, maintaining input subsidy programs, and improving access to land (FAO, 2017). However, there is a need for more comprehensive and sustainable solutions to combat soil erosion in cultivated soils. The government should consider establishing programs that specifically target sustainable development and implement anti-erosion technologies. Mali has committed to defining land degradation neutrality targets (MEADD, 2020), demonstrating its intention to take action and support ongoing initiatives and efforts to achieve land degradation neutrality by 2030. As part of this commitment, it is crucial for the government to prioritize technical measures that promote anti-erosion technologies for cultivated soils. By implementing such measures, the government can contribute significantly to the protection of agricultural lands, the enhancement of food security, and the overall sustainability of agricultural practices in the region.

4.3. Access to credit

Looking at the financial resources, a study conducted by Soumaoro et al., in southern Mali further emphasizes the importance of access to credit in the context of adapting to climate change (Soumaoro et al., 2022). The study highlights how having access to credit is a significant factor that contributes to the ability of farmers to adapt and implement strategies to mitigate the effects of climate change.

Access to credit can significantly enhance the resilience of farmers and rural communities by providing them with the means to invest in climate-resilient practices and resources. It not only empowers farmers to better prepare for the challenges posed by climate change but also offers them opportunities for economic growth and sustainable development. Recent studies in Spain showed that the farmers accept a change in the management only if subsidies are paid (Cerdà et al., 2017; Cerdà & Rodrigo-Comino, 2021). Therefore, credit unions and other financial institutions play a vital role in supporting farmers' adaptive capacity and strengthening their ability to cope with the uncertainties of a changing climate (Soumaoro et al., 2022). Anyway, it appears that access to credit is difficult, mainly due to the lack of guarantees that farmers have to present and the proximity of the agencies.

4.4. Challenges and steps forward to be done

Indeed, while the agricultural sector has been a significant contributor to Mali's Gross Domestic Product, it also faces numerous challenges and weaknesses. One of the primary concerns is its heavy reliance on climatic conditions, making it vulnerable to the impacts of climate change. Soil degradation further exacerbates the sector's vulnerability, leading to decreased productivity and increased fragility of agricultural lands. Obtaining essential inputs and agricultural and financial services is also a significant challenge for farmers in Mali. Limited access to modern agricultural technologies, improved seeds, and financial resources hampers the sector's potential for growth and resilience. However, the most pressing issue in recent years has been the security crisis that has gripped Mali since 2012. The country has faced separatist demands and terrorist attacks, particularly in the northern, central, and southern regions, where agricultural areas have been severely affected. The insecurity has disrupted agricultural activities, displaced farmers, and disrupted supply chains, further adding to the challenges faced by the sector.

According to projections by the Intergovernmental Panel on Climate Change (IPCC) and the CARD tool (Comprehensive Assessment of Resource Use and Efficiency), the production of major crops in Mali, including barley, beans, cassava, cotton, groundnuts, maize, managed grass, millet, peas, rapeseed, rice, sorghum, soy, sugar beet, sunflower, and wheat, is expected to decline significantly. By 2030, a reduction of 12% in crop production is projected, which is expected to worsen to 25% by 2050 due to the impacts of climate change and other challenges (Keita, 2022). Addressing these challenges and vulnerabilities is crucial for the sustainable development of Mali's agricultural sector and its ability to ensure food security and livelihoods for its population. Implementing adaptation strategies, improving access to resources and financial services, and finding solutions to the security crisis are essential steps in strengthening the resilience and productivity of the agricultural sector in Mali.

The economic growth of Mali must be built on improved performance in all aspects of agriculture. The country's agricultural sector possesses several potential strengths and assets that can contribute to its development and growth. These include: i) agro-ecological diversity: Mali's different regions have diverse agro-ecological zones, offering a wide range of climates and conditions suitable for various crops and farming practices; ii) abundant agricultural land: the country has significant potential for agricultural land, which, if effectively utilized, can boost production and increase food security; iii) exploitable water resources: Mali is endowed with substantial water resources, including rivers and lakes, which can be harnessed for irrigation and agricultural development; iv) rich animal resources: the country possesses a diverse range of animal resources, with ample grazing land for livestock rearing; v) potential for aquaculture: Mali has considerable potential for developing aquaculture activities, which can enhance fish production and contribute to food security; vi) forestry and wildlife resources: The country's forests and wildlife resources present opportunities for sustainable forest management and conservation initiatives; vii) young agricultural population: Mali's population is predominantly young and engaged in agriculture, providing a potential workforce for the sector's development; and, viii) structured professional agricultural organizations: the emergence of structured agricultural organizations can facilitate better coordination and collaboration among farmers and stakeholders in the agricultural value chain.

By capitalizing on these strengths and assets, Mali can foster agricultural innovation, increase productivity, promote sustainable practices, and improve livelihoods for its rural population. Strategic investments and supportive policies can help unlock the full potential of the agricultural sector, contributing to overall economic growth and development in the country (MEADD, 2020; Funk et al., 2012).

The government's allocation of a priority budget to the agricultural sector is a crucial step in recognizing its significance for the country's development and food security. With an allocation of approximately 456 billion CFA francs (735 million US$) for financing the 2022-2023 agricultural campaign, the government is demonstrating its commitment to supporting and promoting the sector. This ambitious budget allocation can be instrumental in implementing various initiatives and projects aimed at improving agricultural practices, enhancing productivity, and ensuring sustainable agricultural development. It can support investments in modern agricultural technologies, irrigation systems, research and development, extension services, and infrastructure development in rural areas. Furthermore, a substantial budget allocation for agriculture can also foster the adoption of climate-smart agricultural practices and the implementation of measures to adapt to climate change, considering the vulnerabilities faced by the sector due to climate variability and soil degradation. By investing in the agricultural sector, the government can stimulate economic growth, create employment opportunities, and enhance the livelihoods of rural communities. Additionally, a thriving agricultural sector can contribute to food security, reducing dependency on food imports and increasing domestic food production. However, in addition to the budget allocation, the government must also ensure efficient and transparent utilization of funds, proper implementation of agricultural programs, and coordination among different stakeholders to achieve the desired impact and sustainable development in the sector.

The strategies implemented should: i) enable field surveys to be carried out in rural areas (where 75% of the Malian population lives (Keita, 2022). The studies on farmers' perceptions will make it possible to identify fragile and priority areas, so as to gain a better understanding of the problems they face and envisage sustainable long-term solutions. ii) improve local production by providing farmers with subsidized seed as well as access to credit and microfinance facilities for farm equipment and extension services. iii) improve quality control and ensure the correct application of standards for agricultural inputs, plant products and plant-based foodstuffs. iv) progressively manage land in areas with significant hydro-agricultural potential. v) promote agroforestry, which should make it possible to improve the net productivity of the land, preserve biodiversity and increase the stock of organic carbon in the soil. vi) promote events such as the Environment Fortnight, which are important forums for communicating about the Land Degradation Neutrality process.

4.5. Influence of education

Education is indeed the foundation of progress, and investing in training and applied research institutions is essential for the development of the agricultural sector and the overall progress of the country. Supporting institutions like the IPR/IFRA of Katibougou can help improve the training and capacity building of technicians, engineers, and scientific researchers in various agricultural disciplines. These institutions play a crucial role in providing specialized education, conducting research on agricultural innovations, and disseminating knowledge to farmers and agricultural practitioners.

A study carried out on climate smart agricultural technologies and practices in Nigeria, showed that education and capacity building are crucial in climate change adaptation strategies (Mashi et al., 2022). The education level is found to have a strong influence on the levels of farmers' awareness as shown several study in Mali (Kane et al., 2018), and in Indonesia (Purwanti et al., 2022).

5. Conclusions

Climate change and soil erosion of cultivated soils are not only observed from a scientific point of view but also well perceived by local farmers in the rural municipality of Méguétan. The perceptions of the local population are remarkably consistent with the data obtained from weather stations, thereby validating the accuracy of both the farmers' subjective climate knowledge and the actual meteorological observations. Hot weather, irregular rainfall in terms of quantity, duration and intensity, and the late start and early end of the rainy seasons are all indicators of the changes observed. Farmers use a wide range of traditional techniques to overcome these factors, which drive the food insecurity crisis, and thus keep the soil arable for a long time. Among these measures, the stone rows are the most widely used, due to the extension of the hills around Méguétan. This study could help stakeholders to get significant information and a good understanding of the perception of farmers in Méguétan on erosion control techniques and possible climatic changes they have observed over the last 30 years in particular.

The investigation of the socio-economic aspects of smallholder farmers will enable the Malian government to better understand the pattern of erosion control techniques adopted at the field level to better adapt agricultural production, policy formulation and planning of the cultivated land management and adaptation system to climate change. No aspect of economic, social, political, and cultural development escapes the investigation of rural communities. Therefore, their participation is of utmost importance. The information provide by this study could improve the understanding of policy makers on agricultural adaptation to climate change and soil erosion in Malian Sudano-sahelian zone.

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Author Contributions

ML. Katilé: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing. A. Bengaly: Supervision, Writing - review & editing. S.S. Traoré: Supervision, Writing - review & editing. J. Rodrigo-Comino: Supervision, Writing - review & editing

Data Availability Statement

No applicable.

Conflicts of Interest

The authors declare that there is no conflict of interest and that the funding body had no influence on the results and views presented in this paper.

Appendix: Survey questionnaire

Sample No.:	**Date:**	**Latitude:**	
Altitude:	**longitude:**		
Name of Interviewer:	**Name of Interviewee:**		
No	**Variables**	**Code for option**	**Responses**
1	Region:		
2	Village/Commune:		
3	Ethnicity		
4	Age:		
5	Gender:	1=Male, 2=Female	
6	Education	1= Yes, 2= No	
7	If yes, education level	1= Primary, 2= Fundamental, 3= Secondary, 4= Others, specify	
8	Marital status	1= Married, 2= Single, 3=Widow, 4=Divorce	
9	Household status.	1=Head, 2=Spouse, 3= Others, specify	
10	Current occupation.	1= Farming, 2= Business, 3= Both, 4= Others, specify	
11	Previous occupation	1= Farming, 2= Business, 3= Both, 4= Others, specify	
12	Earning/Month	1= Increasing 2= Decreasing	
13	Expenses/Month	1= Increasing 2= Decreasing	
14	Do you have other sources of income?	1= Yes, 2= No	
15	If yes, specify		
16	Which type of soil do you have?		
17	What is the quality of your soil?		
18	Do you have sufficient land for crop production?	1= Yes, 2= No	
19	Status of the land ownership.	1= Inheritance 2= Bought 3= Rent, 4= Others, specify	
20	Has the size been reduced?	1= Yes, 2= No	
21	If yes, what is the size?		
22	If yes, what is the cause?	1= Soil erosion 2= Flood 3= Others, specify	
23	Which crop do you cultivated?		
24	What is your crop yield of the same land before (in 30 years ago) compared to now?	1= low, 2= high	

25	Which year has been the lowest in term of yield?		
26	Has the temperature changed 30 years ago compared to now?	1= Yes, 2= No	
27	If yes, why.	1= Climate change 2= Low rainfall, 3= Others, specify	
28	Has the yearly first rainfall month changed 30 years ago compared to now?	1= Yes, 2= No	
29	If yes, why.	1= Climate change 2= High temperature, 3= Others, specify	
30	Has the yearly rainfall intensity changed 30 years ago compared to now?	1= Yes, 2= No	
31	If yes, why.	1= Climate change 2= High temperature, 3= Others, specify	
32	Has the yearly rainfall amount changed 30 years ago compared to now?	1= Yes, 2= No	
33	If yes, why.	1= Climate change 2= High temperature, 3= Others, specify	
34	Has the yearly rainfall duration changed 30 years ago compared to now?	1= Yes, 2= No	
35	If yes, why.	1= Climate change 2= High temperature, 3= Others, specify	
36	Have ever heard of climate change?	1= Yes, 2= No	
37	If yes, do you believe that climate change is happening?	1= Yes, 2= No	
38	If yes, what are the signs?		
39	What do you think can be done for climate change adaptation?		
40	Have ever heard of soil erosion?	1= Yes, 2= No	
41	If yes, do you believe it is reducing your crop yield and land size?	1= Yes, 2= No	
42	What do you think can be done to control soil erosion?		
43	Which techniques do you apply against soil erosion?		
44	What are its limitations?		
45	Is the government doing enough for the adaptation and control of Soil erosion?	1= Yes, 2= No	
46	If no, what do you think the government should do?		

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