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Climate Vulnerability and Mining Pressure on the Local Agricultural Economy: An Analysis of Socio-economic and Environmental Impacts in the Village of Kawama (Lualaba, DRC)

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ABSTRACT

This study analyses the combined effects of climate vulnerability and mining pressure on the local agricultural economy in the village of Kawama, Lualaba Province. The aim is to assess the influence of these factors on agricultural performance, the socio-economic conditions of households and environmental degradation. A mixed-methods approach was adopted, combining quantitative and qualitative data collected from 394 farming households selected using stratified probability sampling. The data were analysed using descriptive statistics, Pearson's correlations, analysis of variance (ANOVA), principal component analysis (PCA) and a multiple regression model. The results show that 72 per cent of households are exposed to drought and 68 per cent to erratic rainfall, leading to a decline in agricultural yields of up to 41 per cent. Mining pressure results in soil degradation (81 per cent), water pollution (74 per cent), the presence of mining dust (77 per cent) and a reduction in agricultural land (69 per cent). The correlations reveal a significant negative relationship between agricultural production, climate vulnerability ($r = -0.62$) and mining pressure ($r = -0.71$). The regression model ($R^2 = 0.68$) shows that these two factors account for 68 per cent of the variability in agricultural yields. The study concludes that the interaction between climate change and mining expansion poses a long-term threat to agricultural productivity, food security and the resilience of rural households, highlighting the need for integrated policies on environmental management, the restoration of degraded land and the adaptation of agriculture to climate change.

Keywords: Climate vulnerability, mining pressure, agriculture, Kawama, Lualaba.

1. Introduction

1.1. Background and rationale

The mining areas of Central Africa, and in particular those of the Democratic Republic of the Congo (DRC), are currently at the centre of a dual process of socio-ecological transformation (World Bank, 2024): on the one hand, a rapid intensification of industrial and artisanal mining (Geenen, 2015; Geenen et al., 2020; Geenen & Bikubanya, 2024); and, on the other hand, an increase in climate-related vulnerabilities affecting local agricultural systems (Hilson, 2011; 2016; 2017; Muimba et al., 2022). In the provinces of Haut-Katanga and Lualaba, this complex interaction between extractive pressure and climate variability is profoundly reshaping the conditions of agricultural production and the security of rural livelihoods (Kilela, 2022; Langunu, 2025; Mununga et al., 2023). The provinces of the Congolese Copperbelt are critical areas for the contamination of agricultural soils by heavy metals resulting from mining activities (Mpundu, 2010; Mpundu et al., 2021; Mununga et al., 2023), with concentrations often exceeding international environmental safety thresholds (Cu, Co, Pb, Cd) (Kaniki, 2025; Mpundu et al., 2018; Mununga et al., 2023; Langunu, 2025), leading to the gradual degradation of arable land and a decline in agricultural productivity (Kabala et al., 2020; Kabwe et al., 2020; Atibu et al., 2018; Kaniki, 2025). In this context, studies carried out in the town of Kolwezi and its surroundings confirm that mining activities, particularly around abandoned mines and active extraction sites, are major sources of pollution of soil, sediments and water resources (Mpinda, 2022; Kaniki, 2025; Atibu et al., 2018; Poté et al., 2018). Mining activities cause long-lasting disturbances to agroecological systems (Boisson et al., 2016; Cabala et al., 2018), notably through the contamination of agricultural soils and changes to the physico-chemical properties of arable land, thereby compromising their long-term productivity (Faucon et al., 2015; Pourret et al., 2016; Mpinda, 2021; Kaniki, 2025). These dynamics are particularly critical in rural areas dependent on subsistence agriculture, where the means for economic resilience remain limited.

In the specific context of the village of Kawama, situated in Lualaba Province, these issues take on an even more complex dimension. Indeed, the proximity of mining sites, combined with rain-fed agriculture that is heavily dependent on climatic conditions, exposes communities to a dual vulnerability: ecological (Kilela, 2022; Langunu, 2025; Kikuni et al., 2024) and economic (Nshembe et al., 2026). The fragmentation of agricultural land caused by mining activities profoundly alters land-use patterns and exacerbates socio-environmental imbalances (Kasanda et al., 2020; Geenen, 2015; Kabwe et al., 2021; Mpundu et al., 2021). However, despite several studies on mining pollution and climate vulnerability separately, few studies have integrated these two dimensions into a systemic approach centred on local agricultural economies. This scientific gap limits our understanding of the joint mechanisms through which climate and mining activities interact to influence rural poverty, agricultural productivity and ecosystem degradation.

1.2. Research question

Climate change is now one of the main challenges to the sustainable development of agricultural systems worldwide. According to the IPCC (IPCC, 2022; IPCC, 2023), rising temperatures, changes in rainfall patterns and an increase in extreme weather events are having a profound impact on agricultural productivity, particularly in developing countries where agriculture remains predominantly rain-fed (Hilson, 2016; World Bank, 2024). In sub-Saharan Africa, this situation is of even greater concern due to the heavy reliance of rural populations on subsistence farming, households' limited capacity to adapt, and inadequate agricultural infrastructure (Hilson, 2016; Boko et al., 2007; Mununga et al., 2023). These climatic disturbances undermine agricultural yields, exacerbate food insecurity and heighten the socio-economic vulnerability of rural communities (Nshembe et al., 2026). Alongside the effects of climate change, mining is expanding rapidly in several mineral-rich regions of Africa (Geenen, 2015; Geenen et al., 2020). Although this activity is a major driver of economic growth, it also generates significant environmental pressures (Kikuni et al., 2024). Numerous studies show that mining activities contribute to the contamination of soil and water resources by heavy metals (Katemo et al., 2010; Kashimbo et al., 2016; Muimba et al., 2022; Kaniki, 2025), ecosystem degradation, landscape fragmentation and a reduction in available agricultural land (Kikuni et al., 2025; Useni et al., 2020a; Useni et al., 2024; Atibu et al., 2018; Poté et al., 2018; Faucon et al., 2015). These environmental changes are gradually reducing soil fertility and causing long-term damage to the productive capacity of farms (Mpundu et al., 2018; Kasanda et al., 2022; Langunu, 2025). In the south-east of the Democratic Republic of the Congo, particularly in the provinces of Lualaba and Haut-Katanga, these two dynamics overlap (Kilela, 2022; Kikuni et al., 2024; Useni et al., 2020a; Kaniki, 2025). The expansion of copper and cobalt mining is taking place against a backdrop of high climate variability, thereby exacerbating the pressures on agricultural systems. Research by Kabala et al. (2020), Kabwe et al. (2024) and Useni et al. (2024) show that the expansion of mining activities is gradually reducing arable land, degrading soils and intensifying land-use conflicts between agriculture and mining. This situation undermines the livelihoods of rural households whose incomes and food security rely primarily on agriculture.

The village of Kawama perfectly illustrates this dual environmental constraint. This village is situated at the heart of the Lualaba mining basin, characterised by the proximity of large mining operations and by smallholder farming that is heavily dependent on rainfall. Farming households their face, simultaneously, erratic rainfall, recurrent droughts, soil degradation, pollution of water resources and a gradual reduction in arable land. These factors interact and reinforce their negative effects on agricultural production, household incomes, food security and the resilience of rural communities. However, although numerous studies have analysed the impacts of climate change (IPCC, 2022; IPCC, 2023; Boko et al., 2007) and those of mining activities (Atibu et al., 2018; Poté et al., 2018; Useni et al., 2024), very few studies have adopted an integrated approach that examines the interactions between climate vulnerability, mining pressure, agricultural performance and the socio-economic conditions of households in mining areas of the Democratic Republic of the Congo. This knowledge gap limits our understanding of the mechanisms through which these two factors reinforce one another and undermine the sustainability of agricultural systems. It is against this backdrop that the present study is conducted, seeking to answer the following central question:

How do climate vulnerability and mining pressure interact to influence agricultural performance, socio-economic conditions and environmental degradation in the village of Kawama (Lualaba, DRC)?

Specifically,

1. To what extent does climate variability influence agricultural yields and household food security in Kawama?

2. What are the effects of mining activities on soil and water quality and on the availability of agricultural land in the study area?

To answer these questions, the following hypotheses were formulated:

1.3. Research hypotheses

H1: Climate variability (irregular rainfall, droughts, floods) significantly reduces agricultural yields and undermines the food security of farming households.

H2: Mining activities contribute to soil degradation, water contamination and a reduction in the amount of available agricultural land in Kawama.

H3: The interaction between mining pressure and climate vulnerability exacerbates rural poverty and reduces the socio-economic resilience of farming households.

1.4. Objectives of the study

1.4.1. Overall objective

To analyse the interactions between climate vulnerability and mining pressure and their effects on agricultural performance, the socio-economic conditions of households and environmental degradation in the village of Kawama (Lualaba, DRC).

1.4.2. Specific objectives

1. To assess the effects of climate variability on agricultural production and food security among farming households in Kawama.

2. To analyse the impact of mining activities on soil quality, water resources and agricultural land in the village of Kawama.

3. To examine the combined interactions between mining pressure and climate vulnerability on the socio-economic conditions of rural populations.

2. Literature review

2.1. Climate vulnerability and agriculture in Africa

Scientific literature shows that African agriculture is highly exposed to the effects of climate change. According to the IPCC (IPCC, 2022; IPCC, 2023), agricultural systems in developing countries are among the most vulnerable due to their heavy reliance on rainfall and their limited capacity to adapt. Hilson (2016) confirms that sub-Saharan Africa is already experiencing rising temperatures and erratic rainfall, which are directly affecting agricultural production.

Similarly, Boko et al. (2007) highlight that climatic variations in West and Central Africa are leading to a decline in the yields of food crops. Hilson (2011) adds that local knowledge constitutes an important adaptation mechanism, but one that is insufficient in the face of intensifying climate shocks.

2.2. Agricultural resilience and the vulnerability of rural systems

Vogel et al. (2007) show that vulnerability results from the exposure, sensitivity and adaptive capacity of rural communities. Williams (2018) points out that smallholder farmers in Africa are particularly vulnerable due to poor infrastructure and limited access to resources. Cáceres (2021) proposes a spatial framework for assessing climate vulnerability, highlighting the importance of integrated approaches combining environmental and socio-economic data.

2.3. Mining pressure and environmental degradation

In mining areas around the world, soil contamination is a major factor in environmental degradation. Mpinda et al. (2021) and Mpundu et al. (2021) show that heavy metals from mining activities (Cu, Pb, Cd, Co) persist in the soil and affect crops. Faucon et al. (2015) and Lambers et al. (2015) demonstrate that soil contamination alters soil–plant interactions and reduces agricultural productivity. In the DRC, Atibu et al. (2018) show that the aquatic and agricultural systems of Katanga are heavily contaminated by mining activities. Poté et al. (2018) confirm the presence of heavy metals in mining areas of Central Africa, posing high risks to food security. Devarajan et al. (2017) add that aquatic ecosystems near mining sites are experiencing rapid degradation in their ecological quality.

2.4. Agricultural dynamics and socio-economic impacts

Kabala et al. (2020) show that in Lualaba, the degradation of agricultural land linked to mining activities reduces yields and increases the vulnerability of rural households. Kabwe et al. (2024) highlight that mining pressure leads to competition for land between agriculture and mining, reducing access to arable land. Useni et al. (2024) demonstrate, through an analysis of landscape dynamics in Lualaba, that mining expansion leads to the fragmentation of agricultural land and a loss of vegetation cover.

2.5. Agriculture, adaptation and structural changes

Karume et al. (2022) and Nshembe (2026) show that climate-smart agriculture (CSA) is expanding in the DRC, but remains limited by institutional and technical constraints.

3. Methodology

3.1. Study area

Figure 1. Map of the study area (villages around the Lualaba mining sites)

This study was conducted in the village of Kawama, located in Lualaba Province, in the south-east of the Democratic Republic of the Congo. This area forms part of the Congolese Copperbelt mining region, characterised by a significant intensification of copper and cobalt extraction activities, alongside subsistence farming that is heavily dependent on climatic conditions. The study area is characterised by the coexistence of industrial and artisanal mining activities alongside family-based farming systems. This situation places significant pressure on natural resources, particularly agricultural land, soil and water resources. Furthermore, the area experiences significant climate variability, characterised by erratic rainfall, prolonged periods of drought and episodes of flooding, which directly affect agricultural activities.

3.2. Study population

The target population for this research consists of 24,675 farming households, according to data from the Lualaba Health Zone and local administrative services (Census Report, November 2025). These households constitute the primary unit of analysis, as they are directly involved in agricultural activities and are the first to be exposed to the combined effects of climate variability and mining pressures. These households rely primarily on subsistence farming and have limited capacity to adapt to environmental shocks. They therefore represent a particularly relevant population for analysing the interactions between climatic, environmental and socio-economic factors.

3.3. Sampling

The study employs stratified probability sampling to ensure better representativeness of the different areas of exposure to mining activities and the agro-ecological conditions in the village of Kawama. The sample size was determined using Slovin's formula:

$\mathbf{n} = \frac{\boldsymbol{N}}{\mathbf{1}+\boldsymbol{N}(\boldsymbol{e}^{\mathbf{2}})}$ where N represents the total population (24,675 households) and e is the margin of error set at 5 per cent, i.e. 0.05. The calculation yields a sample of approximately 394 households. Consequently, a total of 394 farming households were surveyed as part of this study over a period of 8 days (from 23 to 3 February 2026, excluding Saturdays and Sundays), taking into account their spatial distribution, the intensity of agricultural activities, the area under cultivation and their proximity to mining areas.

3.4. Data collection methods

This research adopts a mixed-methods approach, combining quantitative and qualitative methods to better understand the complex dynamics between climate vulnerability, mining pressure and the agricultural economy. Primary data were collected through structured questionnaires administered to selected farming households between 15 and 23 May 2026. These questionnaires facilitated the collection of information on agricultural yields, production losses, perceptions of climate change, and the impacts of mining activities on agricultural land and household incomes. In addition, semi-structured interviews were conducted with heads of households, farmers and certain local authorities to gain a better understanding of the adaptation strategies implemented in response to environmental constraints between 23 and 30 May 2026. Direct observation of agricultural areas and mining sites also helped to document landscape changes and visible signs of environmental degradation. Secondary data were drawn from institutional reports, notably those of the IPCC, provincial agricultural services, scientific studies carried out in the Lualaba region, and academic articles published in indexed scientific journals.

3.5. Study variables

The dependent variables in this study primarily concern households' agricultural performance, measured in terms of yields, agricultural production and the level of food security. They also include households' socio-economic conditions, notably income, diversification of activities and economic resilience. The independent variables consist of climate vulnerability and mining pressure. Climate vulnerability is analysed through rainfall variability, droughts and floods, whilst mining pressure is assessed on the basis of proximity to mining sites, soil contamination and access to agricultural land. Intermediate variables such as soil and water quality, access to agricultural land and household adaptation strategies are also taken into account in order to better understand the mechanisms of interaction between the factors under study.

3.6. Data analysis methods

The data collected as part of this study were analysed using complementary quantitative and qualitative approaches to facilitate an in-depth understanding of the interactions between climate vulnerability, mining pressure and agricultural performance. Initially, descriptive statistics were used to summarise the socio-economic characteristics of the households surveyed, as well as the general trends observed. This approach is recommended by Field (2018) and Wooldridge (2016), who emphasise the importance of descriptive statistics in the exploratory analysis of socio-economic data. Subsequently, a correlation analysis was carried out to identify the relationships between climatic, mining and agricultural variables. According to Gujarati & Porter (2009), this method measures the strength and direction of relationships between variables prior to any advanced econometric modelling. Subsequently, multiple linear regression was used to assess the combined effect of climate vulnerability and mining pressure on households' agricultural performance. This method is widely used in applied economics and environmental sciences, as highlighted by Wooldridge (2016) and Greene (2018), as it isolates the specific effect of several explanatory variables on a dependent variable. The qualitative analysis of the interviews was carried out using a thematic approach, in accordance with the recommendations of Braun & Clarke (2006), in order to identify local perceptions, adaptation strategies and social representations of climate and mining impacts. Finally, the analyses were contextualised by taking into account health and administrative data provided by the Lualaba Health Zone, which constitutes an official reference source for the population of 24,675 households and for understanding the socio-health and demographic dynamics of the study area.

SPSS and Excel software were used for data processing and statistical analysis.

3.7. Conceptual framework for the impacts of climate vulnerability and mining pressure on the agricultural economy in the village of Kawama

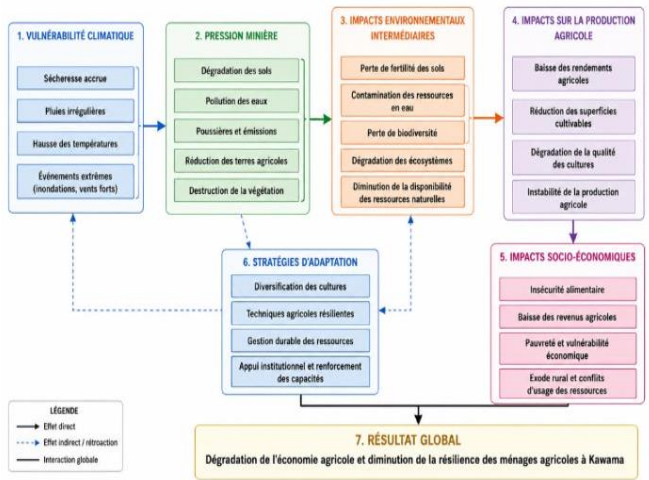

Figure 2. Conceptual framework of climate vulnerability and mining pressure in Kawama

4. Results

4.1. Effects of climate vulnerability on agricultural production in Kawama

This section presents the results relating to the impact of climate variations on the agricultural activities of households in the village of Kawama. The analysis focuses on households' exposure to the main climate hazards and their measured effects on agricultural yields.

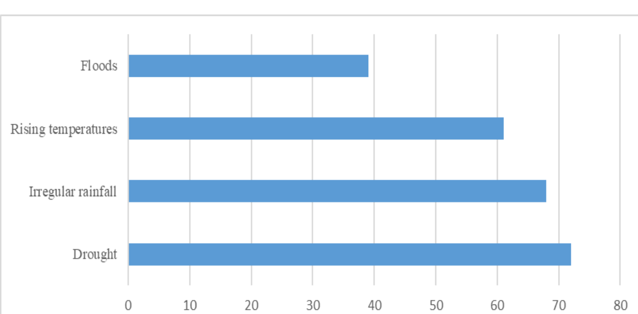

Figure 3. Households' exposure to climate shocks Affected households (%)

The results in Figure 3 show that drought is the predominant climatic hazard observed in the village of Kawama. With an exposure rate of 72 per cent, drought appears to be the climatic phenomenon that most significantly shapes the organisation of local agricultural activities. This situation is confirmed by the households' responses, which indicate a reduction in water availability during critical periods of crop growth. Irregular rainfall, affecting 68 per cent of households, is also a major factor disrupting the agricultural calendar. Respondents report that the unpredictability of the seasons makes it difficult to plan sowing, leading to seed losses and a reduction in the area of land that is actually productive. Rising temperatures, mentioned by 61 per cent of households, are perceived as a factor exacerbating soil drying and shortening the growing season. Irregular rainfall is also a major factor in productivity losses, as it disrupts the phenological cycles of crops. Flooding (39 per cent), although less frequent, causes sporadic but significant losses due to the destruction of standing crops. Drought represents the most adverse situation, with a reduction in production of over 40 per cent. These findings reveal that farming households in Kawama face a combination of climatic hazards that simultaneously affect water availability, soil fertility and the stability of agricultural cycles.

4.2. Variation in agricultural yields according to climatic conditions

The results show significant variation in agricultural yields depending on climatic conditions.

Table 1. Agricultural yields by climate shock

Climate conditions	Yield (t/ha)	Variation (%)
Normal conditions	2.9	0
Drought	1.7	-41
Irregular rainfall	1.9	-35
Floods	2.1	-28

Data from the field survey in May 2026

Agricultural yields vary significantly depending on the type of climatic conditions to which households are exposed. Under normal conditions, average yields reach 2.9 tonnes per hectare. However, during periods of drought, these yields fall to 1.7 t/ha, representing an average loss of 41 per cent. In the event of erratic rainfall, yields stand at 1.9 t/ha, a decrease of 35 per cent. Flooding, meanwhile, leads to a reduction to 2.1 t/ha, corresponding to a loss of 28 per cent.

4.3. Effects of mining pressure on agricultural resources

This section presents the findings regarding the impacts of mining activities on agricultural resources in the village of Kawama. The analysis focuses on soil quality, the availability of agricultural land and the pollution of natural resources.

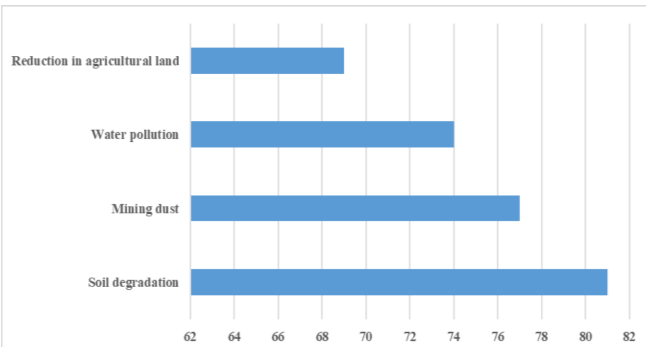

Figure 4. Impacts of mining pressure Households affected (%)

The results show that mining pressure has a significant influence on environmental conditions in the village of Kawama. Soil degradation is reported by 81 per cent of the households surveyed, making it the most widely perceived impact. Water pollution is mentioned by 74 per cent of households, whilst dust from mining activities affects 77 per cent of respondents.

Furthermore, 69 per cent of households report a gradual reduction in available agricultural land, mainly due to the expansion of mining sites and the degradation of arable land. These findings confirm that soil degradation is the most significant impact of mining activities in the village of Kawama. This situation results in a gradual decline in the fertility of agricultural land, rendering some plots unsuitable for cultivation. Dust generated by mining activities also constitutes a major constraint, directly affecting crops and reducing plant photosynthesis. Water pollution is widely observed by households, limiting access to good-quality water for irrigation and domestic use. Finally, the reduction in available agricultural land reflects growing competition for land between mining and agricultural activities, leading to a decrease in the area of land cultivated by households.

4.4. Agricultural yields according to distance from mining areas (ANOVA)

This section presents a comparison of average agricultural yields based on the distance of farms from mining areas in the village of Kawama.

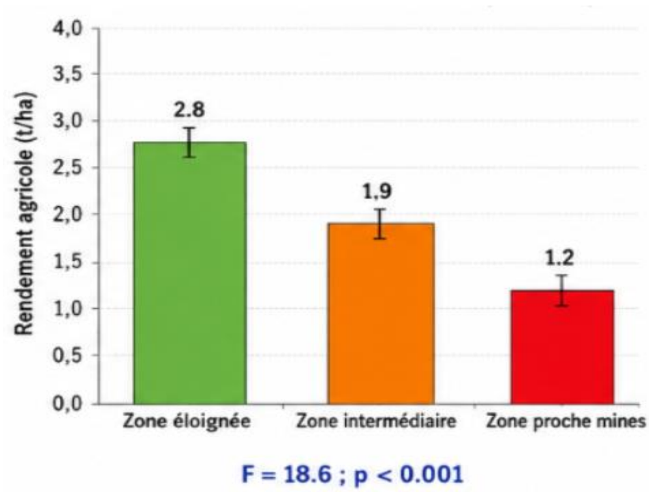

Figure 5. Agricultural yields by distance from mining areas (ANOVA)

This graph shows that households located in areas far from the mines have the highest agricultural yields, with an estimated average production of 2.8 tonnes per hectare. This level of production reflects conditions favourable to farming, notably lower exposure to mining dust, better soil quality and a more stable supply of the environmental resources necessary for crop growth. By contrast, in intermediate areas, yields fall significantly to 1.9 tonnes per hectare. This decline reflects an initial form of gradual deterioration in agro-environmental conditions. At this level, households begin to experience the indirect effects of mining activities, including the dispersion of fine particulate matter, disruption to soil quality and a degree of instability in local ecological conditions. This zone is thus a transition zone where the effects of mining pressure are noticeable but still partially mitigated. In areas close to mining operations, agricultural yields fall to 1.2 tonnes per hectare. This significant decrease reflects a severe deterioration in agricultural production conditions. Soils are more severely affected, environmental pollution is more intense, and the constraints linked to mining activities are more direct and continuous. This situation leads to a significant reduction in agricultural productivity and highlights the high vulnerability of agricultural systems located in the immediate vicinity of mining sites. Figure 5 illustrates a clear and progressive variation in agricultural yields according to the level of exposure to mining activities, confirmed by a statistically significant ANOVA test (F = 18.6;

p < 0.001). The statistical analysis confirms that these differences are not due to chance, but are statistically significant ($p < 0.001$). This means that distance from mining areas is a determining factor in the variation in agricultural yields in Kawama. The observed trend follows a clear and structured downward pattern, illustrating a gradient of negative impact of mining activities on agricultural production.

4.5. Principal Component Analysis (PCA)

This section presents the results of the principal component analysis (PCA) applied to the environmental, climatic and socio-economic variables of the village of Kawama. This analysis aims to reduce the dimensionality of the data and to identify the major underlying factors that explain the overall variability of the system under study.

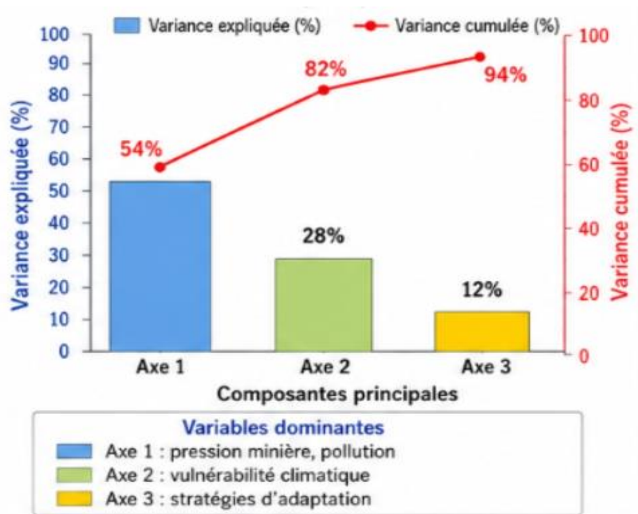

Figure 6. Principal Component Analysis (PCA)

The results show that three principal components are sufficient to explain a very large proportion of the total variance observed in the data, thus reflecting a strong structuring of the phenomena studied around a few dominant factors. The first component, known as Axis 1, accounts for 54 per cent of the total variance on its own. It is strongly associated with variables linked to mining pressure, notably soil pollution, environmental degradation and the presence of dust resulting from extractive activities. This component therefore represents the main factor structuring the dynamics observed in the study area. It reveals that mining pressure is the central determinant of environmental and agricultural changes in Kawama, encompassing the most significant effects on the quality of natural resources. The second component, Axis 2, accounts for 28 per cent of the total variance and is primarily linked to climate vulnerability. It encompasses variables relating to rainfall variability, drought episodes and temperature fluctuations. This component reflects the importance of climatic factors in shaping the agricultural system, even though their influence is less than that of mining activities. It shows that climate remains a determining factor, but one that is secondary to the anthropogenic pressure exerted by mining activities.

The third component, Axis 3, which accounts for 12 per cent of the total variance, is associated with the adaptation strategies implemented by farming households. This component reflects local responses to environmental constraints, notably adjustments to agricultural calendars, crop diversification and survival practices. Although its weight is lower, it remains significant as it represents the populations' capacity to adapt to the combined shocks of climate and mining activities. This figure shows that 94 per cent of the total variance is explained by these three components, indicating a high degree of structural consistency in the data

4.6. Correlation between climate, mining and agriculture

Table 2 presents the correlation matrix between the main variables of the study, notably agricultural production, climate vulnerability and mining pressure. This correlation analyses the nature and strength of the statistical relationships between these variables in order to understand their interaction in the context of the village of Kawama.

Table 2. Correlation matrix (Pearson)

Variables	Agricultural production	Climate vulnerability	Mining pressure
Agricultural production	1	-0.62	-0.71
Climate vulnerability	-0.62	1	0.38
Mining pressure	-0.71	0.38	1

These results reveal significant and consistent relationships between the variables studied and the structural links within the local agricultural system. The first relationship observed is that between agricultural production and climate vulnerability. The correlation coefficient is negative ($r = -0.62$), indicating a moderate inverse relationship. This means that as climate vulnerability increases, agricultural production tends to decrease significantly. This relationship reflects the direct impact of climatic disturbances on agricultural performance, notably through reduced water availability, disruption to agricultural cycles and lower crop productivity. The second relationship concerns agricultural production and mining pressure. The correlation coefficient is also negative and stronger (r = -0.71), indicating a strong inverse relationship. This means that the intensification of mining activities is associated with a more pronounced decline in agricultural yields. This relationship highlights the major role played by mining-related environmental degradation – notably soil pollution, water contamination and the reduction in arable land – which directly affects the productive capacity of farming households. The third relationship observed is that between climate vulnerability and mining pressure, with a weak positive coefficient (r = 0.38). This suggests that areas heavily affected by mining activities also tend to be slightly more vulnerable to climate shocks. This relationship can be explained by overall environmental degradation, which reduces the resilience of agricultural ecosystems to climatic variations. Overall, this table shows that all relationships are statistically consistent and follow logical patterns. The negative relationships between agricultural production and the two explanatory factors confirm that agricultural performance is strongly influenced by environmental and factors. As the strongest relationship is that between mining pressure and agricultural production, this confirms that mining activities are the most decisive factor in the decline in agricultural yields in Kawama.

4.7. Multiple Regression

Figure 7 presents the results of the multiple regression model estimating the combined effect of climate vulnerability and mining pressure on agricultural production in the village of Kawama. This model measures the importance of each explanatory factor in the variation in observed agricultural yields.

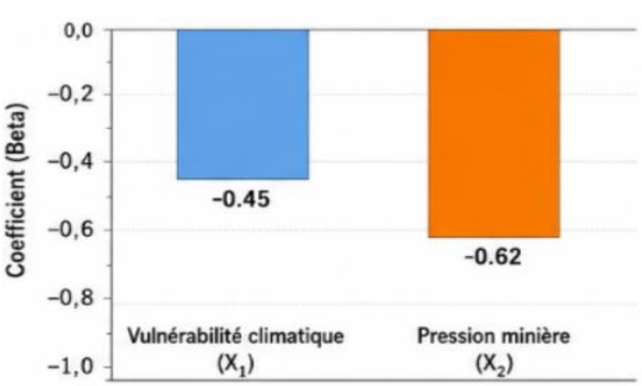

Figure 7. Multiple Regression

The results show a significant negative relationship between the explanatory variables and agricultural production, meaning that an increase in environmental constraints leads to a gradual decline in agricultural performance. The first explanatory variable is climate vulnerability, represented by a negative coefficient of -0.45. This means that an increase in climate vulnerability leads to a reduction in agricultural production. This influence reflects the direct effects of climate disturbances on agricultural systems, notably through reduced water availability, disruption to agricultural timetables and a decline in crop productivity. Although its effect is significant, it remains smaller than that of mining pressure. The second variable is mining pressure, with a higher coefficient in absolute terms of -0.62. This indicates that mining pressure has a stronger impact on agricultural production than climate vulnerability. This greater influence is explained by the direct degradation of agricultural resources, notably soil contamination, water pollution and a reduction in arable land. Thus, mining activities are the most decisive factor in the decline in agricultural yields in Kawama. The overall model has a coefficient of determination R^2 of 0.68, meaning that 68 per cent of the variation in agricultural production is explained by the two variables included in the model. This level of explanation indicates good model performance and confirms that the combination of climatic and mining factors plays a major role in local agricultural dynamics. Model: $Y = 3.12 – 0.45X_1 – 0.62X_2$

4.8. Projection of agricultural production in Kawama

This section presents a projection of trends in agricultural production in the village of Kawama over a future period, based on trends observed in the empirical data. This projection anticipates the dynamics of agricultural production in light of the persistence of the climatic and mining pressures identified in the study.

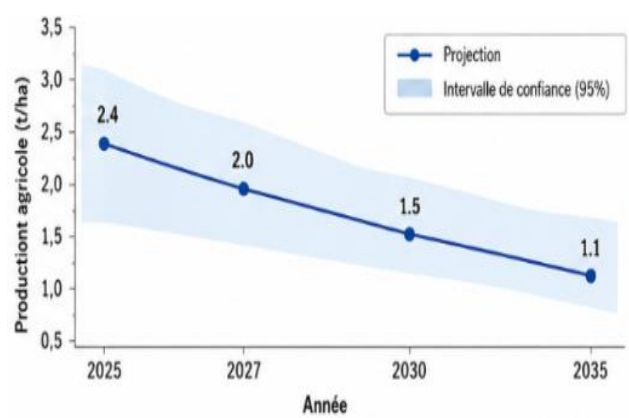

Figure 8. Projection of agricultural production in Kawama

This trend line shows a clear downward trend in agricultural production over time. This decline is not abrupt but gradual, indicating a structural and ongoing deterioration of the local agricultural system rather than an isolated, one-off shock. At the start of the projection period, agricultural production is at a higher level, corresponding to the current conditions observed in the study area. However, over time, a steady decline is observed, reflecting the cumulative negative effects linked to climate vulnerability and mining pressure. This trend shows that Kawama's agricultural systems are subject to persistent constraints that are gradually reducing their productive capacity. This gradual decline in production is the combined result of several factors already identified in previous analyses, notably soil degradation, water pollution, the reduction in agricultural land and unstable climatic conditions. The cumulative effect of these factors leads to a gradual loss of agricultural yield. The projection also shows a lack of stabilisation or recovery in agricultural production over the period under consideration. This means that, in a context where environmental pressures remain constant or are increasing, the local agricultural system lacks sufficient natural mechanisms for recovery or compensation. Figure 8 illustrates a worrying trend of continuous decline in agricultural production in Kawama.

4.9. Qualitative analysis

This analysis was carried out to supplement and expand on the quantitative findings, whilst identifying the perceptions, experiences and adaptation strategies of farming households in the face of climate vulnerability and mining pressure.

4.9.1. Households' perceptions of climate change

Almost all those interviewed acknowledge that there has been a significant change in climatic conditions over recent years. Participants describe a gradual shortening of the rainy season, an increase in episodes of drought, and significant irregularity in the agricultural calendar. Several farmers explain that the rains now arrive several weeks late or stop abruptly during the growing season. This situation leads to the loss of seedlings and forces some households to carry out several sowing cycles in the course of a single season, thereby increasing production costs. The interviews also reveal that temperatures are perceived as being increasingly high, causing the soil to dry out rapidly and reducing the availability of water for crops. One farmer sums up the situation by saying: "Before, we knew exactly when the rains would come. Now, we sow without knowing whether the rain will continue. Many fields dry out before harvest."

4.9.2. Perceptions of the impacts of mining activities

The interviews reveal a strong consensus regarding the negative effects of mining activities on the agricultural environment. Households report observing a gradual deterioration of arable land located near mining operations. According to participants, dust from lorries and extraction sites covers the crops, stunting their growth and reducing their yield. Several farmers also report unusual discolouration of certain water sources, as well as the gradual disappearance of several small watercourses formerly used for irrigation and domestic needs. Local authorities emphasise that the expansion of mining concessions is gradually reducing the land available for smallholder farming, creating significant competition between mining and agricultural production.

As one traditional leader puts it: 'Every year, the amount of farmland is decreasing because the mines are taking up new areas. Young people would rather work in the quarries than farm.'

4.9.3. Socio-economic consequences for farming households

The qualitative findings show that the decline in agricultural production is leading to a significant reduction in household incomes. Several families report having reduced the number of daily meals during certain periods of the year due to poor harvests. Other households indicate that they are forced to buy foodstuffs that they previously produced themselves.

The interviews confirm an increase in economic dependence on artisanal mining activities. Many young people are gradually abandoning farming to seek quick s of income at mining sites. According to respondents, this situation further undermines local agricultural production and exacerbates food insecurity.

One participant explains: "Our children are leaving the fields to go and dig in the mines. We are left on our own to farm, whilst the harvests are shrinking every year."

4.9.4. Local adaptation strategies

Faced with this dual pressure from climate change and mining, households are developing several adaptation strategies. The main strategies mentioned are moving fields to less degraded areas, crop diversification, combining crop and livestock farming, engaging in non-agricultural income-generating activities, running small local businesses, and taking on temporary work in mining operations. However, the majority of participants believe that these strategies remain insufficient to offset the agricultural losses observed. Farmers also highlight the lack of technical support, access to improved seeds, water conservation infrastructure and government support programmes.

4.9.5. Expectations expressed by the communities

The people interviewed put forward several recommendations to improve their living conditions.

The main expectations relate to strengthening environmental oversight of mining companies, the rehabilitation of degraded land, compensation for households that have lost their agricultural land, support for climate-resilient agriculture, the creation of irrigation systems, and training for farmers in agricultural techniques adapted to new climatic conditions. Local authorities also emphasise the need for better coordination between agricultural, environmental and mining departments in order to minimise land-use conflicts.

5. Discussion of the results

The findings of this study confirm a significant deterioration in the agricultural economy of the village of Kawama as a result of climate vulnerability and mining pressure. The integrated analysis of the data shows that these two factors do not operate in isolation, but interact within a complex system that is gradually undermining the productive capacities of farming households.

5.1. Climate vulnerability and agricultural dynamics

The results show that 72 per cent of farming households are exposed to drought, 68 per cent to erratic rainfall and 61 per cent to rising temperatures. This high level of climate exposure leads to a significant drop in crop yields, falling from 2.8 t/ha in favourable areas to 1.2 t/ha in the most affected areas – a reduction of 41 per cent. Households report increasing difficulty in anticipating agricultural seasons, leading to delays in sowing, seed losses and a reduction in the area actually cultivated. These findings are consistent with the work of the IPCC (2022, 2023), which highlights that African agricultural systems are among the most vulnerable to climate variability. Similarly, Hilson (2016) and Boko et al. (2007) show that sub-Saharan Africa is particularly vulnerable to rainfall irregularities. Morton (2007) and Lobell et al. (2011) confirm that these climatic disturbances lead to a structural decline in agricultural yields, which corresponds directly to the trends observed in Kawama.

5.2. Mining pressure and environmental degradation

The results indicate that 81 per cent of household's report soil degradation, 74 per cent report water pollution, 77 per cent report significant levels of mining dust, and 69 per cent report a reduction in agricultural land. These findings reveal very high mining pressure on the agricultural environment. A gradual reduction in agricultural land is also observed, linked to the expansion of mining areas and the degradation of arable land. These findings are consistent with the work of Mpinda (2021); Langunu (2025); Kilela (2022); Mpundu (2010); Mpundu et al. (2018) and Amisi et al. (2018), which show that mining activities lead to the accumulation of heavy metals in agricultural soils. Alloway (2013) and Mpundu et al. (2021); Mpinda (2022) confirm that this contamination reduces soil fertility and directly affects agricultural productivity. Tchounwou et al. (2012) and Kasanda et al. (2020) also emphasise that the toxicity of heavy metals has a direct impact on crop growth and food security. In the African context, Yousefi et al. (2018) and Mensah et al. (2020) demonstrate the significant pressure exerted by mining activities on agricultural land, leading to its gradual degradation.

5.3. Decline in agricultural yields and food security

Analyses reveal a significant negative correlation between agricultural production and climate vulnerability ($r = -0.62$) as well as between agricultural production and mining pressure ($r = -0.71$). This means that as these two factors increase, agricultural production decreases (a significant decline in agricultural yields in line with exposure to climatic and mining factors). This decline in agricultural performance results in a weakening of household food security and an increase in their economic vulnerability. These findings are consistent with those of Boisson et al. (2016) and Tilman et al. (2017), who show that the degradation of agricultural land leads to a sustained decline in global food production. Foley et al. (2011) add that the conversion of agricultural land into industrial zones poses a major threat to food systems. Barrett and Carter (2013) and Dorward et al. (2009) explain that falling agricultural yields increase rural poverty and reduce households' ability to cope with economic shocks, which is consistent with the trends observed in Kawama.

5.4. Interaction between climate and mining pressure

The ANOVA analysis reveals significant differences in agricultural yields according to distance from the mines: 2.8 t/ha in the distant zone; 1.9 t/ha in the intermediate zone; and 1.2 t/ha in the nearby zone ($F = 18.6$; $p < 0.001$). This confirms the strong interaction between climate vulnerability and mining pressure. The analyses show that the areas most exposed to mining activities (Mutanda Mining and DEZIWA) are also more sensitive to climate effects, which exacerbates the degradation of agricultural systems. This dynamic is confirmed by IPBES (2019) and the IPCC (2022), which emphasise that climatic and anthropogenic pressures act cumulatively on ecosystems. Thornton and Lipper (2014) and Harvey et al. (2018) demonstrate that African agricultural systems face a dual environmental constraint that significantly reduces their resilience.

5.5. Findings from the statistical analyses

The regression model indicates that climate vulnerability ($\beta = -0.45$) and mining pressure ($\beta = -0.62$) account for 68 per cent of the variation in agricultural production ($R^2 = 0.68$). Statistical analyses confirm the robustness of the observed relationships. The negative correlations between agricultural production, climate and mining pressure indicate a significant inverse relationship between these variables. The regression model shows that these two factors account for a large proportion of the variation in agricultural yields, confirming their decisive role in the observed dynamics. These results are consistent with the work of Wooldridge (2016), Greene (2018) and Gujarati & Porter (2009), who emphasise the importance of econometric models in the analysis of complex socio-economic phenomena. The principal component analysis supports the conclusions of Jolliffe (2002), revealing the structural dominance of mining pressure in the organisation of the variables studied. In the context of the Democratic Republic of the Congo, these results confirm the findings of Kabala et al. (2020), which show severe degradation of agricultural land in the mining areas of Lualaba. Useni et al. (2024) also highlight the rapid transformation of agricultural landscapes driven by mining expansion. Karume et al. (2022) reveal the limitations of agricultural adaptation strategies in the face of environmental pressures, which explains the low resilience observed in the study area. This study shows that the decline of the agricultural economy in Kawama results from a combination of two major factors: climate vulnerability and mining pressure. These two factors interact and reinforce each other's negative effects, leading to a gradual decline in agricultural yields and a weakening of rural households' livelihoods.

5.6. Qualitative findings

The qualitative findings confirm and reinforce the observations drawn from the quantitative analyses. Household accounts show that climatic disturbances, characterised by prolonged droughts, erratic rainfall and rising temperatures, directly affect agricultural timetables and reduce farm productivity. At the same time, mining activities are perceived as a major source of soil degradation, pollution of water resources and a reduction in arable land, thereby exacerbating the vulnerability of rural communities. Interviews also reveal that declining agricultural incomes are gradually driving households – particularly young people – towards artisanal mining, which further exacerbates the disruption of the local agricultural system. Despite the implementation of certain adaptation strategies, such as crop diversification or the relocation of fields, local people feel that their capacity for resilience remains limited due to a lack of institutional and technical support. These findings corroborate the conclusions of the statistical analyses, which show that climate vulnerability and mining pressure are the main factors explaining the decline in agricultural production and the weakening of livelihoods among households in the village of Kawama.

Conclusion and Recommendations

The aim of this study was to analyse the interactions between climate vulnerability and mining pressure, as well as their effects on agricultural performance, the socio-economic conditions of households and environmental degradation in the village of Kawama, Lualaba Province. The results confirm that the local agricultural economy is subject to a dual environmental constraint, the effects of which reinforce one another. The analysis shows that climate variability is a major factor in the fragility of agricultural systems: drought (72 per cent) and erratic rainfall (68 per cent) lead to yield losses of up to 41 per cent, directly compromising households' production and food security. Furthermore, mining pressure appears to be an even more significant determinant of agricultural degradation, through soil deterioration (81 per cent), water pollution (74 per cent), mining dust (77 per cent) and the reduction in available agricultural land (69 per cent). Statistical analyses confirm these trends, revealing significant negative correlations between agricultural production and climate vulnerability ($r = -0.62$) as well as between agricultural production and mining pressure ($r = -0.71$). The regression model indicates that these two factors account for 68 per cent of the variation in agricultural performance, confirming the hypotheses put forward.

Thus, the decline of the agricultural economy in Kawama is not the result of a single factor, but of a complex interaction between climate change and transformations linked to mining activities. This situation is gradually reducing the resilience of farming households and threatening the sustainability of rural livelihoods.

In light of these findings, it is recommended that environmental governance of mining activities be strengthened through increased monitoring of discharges, the rehabilitation of degraded land and the protection of water resources. It also appears necessary to promote climate-resilient agriculture through the dissemination of adapted crop varieties, the improvement of soil and water conservation techniques, the development of irrigation systems and the provision of technical support to farmers. Finally, an integrated approach involving agricultural services, environmental authorities, mining companies and local communities is essential in order to reconcile mining operations with the protection of ecosystems and the sustainable maintenance of local agricultural economies.

Future prospects suggest extending the research to other mining areas in Lualaba in order to compare local dynamics, incorporate climate data over a longer period to analyse evolving trends, and study local adaptation strategies among farming households in greater depth, with a view to proposing more appropriate and sustainable public policies.

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