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Chapter 2

Climate risks and evolution of physicochemical parameters of soils of hydro-agricultural developments in the Nariarlé watershed from 1997 to 2022 , Burkina Faso

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Abstract

This study of climatic risks and evolution of the physicochemical parameters of the soils of the irrigation facilities of the Nariarlé watershed, Nakanbé sub-basin in Burkina Faso from 1997 to 2022, was based on documentary exploitation and Results of soil sample analyses according to the coordinates of the 1997 profiles. Irrigation schemes in the Nariarlé watershed are facing risks related to climate change. Their levels of exposure and vulnerability remain very high. The analysis methodology is based on three parts. The objective is to analyze the effects of extreme variations in climatic parameters on the evolution of the physicochemical parameters of soils in irrigation schemes. The samples were analyzed by the laboratory of the National Bureau of Soils (BUNASOLS). The results indicate that climate change influences the texture at three (0.3) fractions, carbon, organic matter and exchangeable bases of soils in irrigated schemes. To ensure food security and strengthen the economy of States, it is crucial to put in place effective strategies and techniques for adapting to the climatic risks of irrigation schemes in Africa.

Keywords: irrigation developments, climate change, Nariarlé, Burkina Faso

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1. Introduction

This study of climatic risks and evolution of soil physicochemical parameters of irrigation schemes in the Nariarlé watershed, Nakanbé sub-basin in Burkina Faso from 1997 to 2022, was based on documentary and of the results of Analyzes of soil samples according to the coordinates of the 1997 profiles. Irrigation schemes in the Nariarlé sub-watershed are faced with risks linked to climate change (Sampebgo, Ibrahim, et al., 2024, p. 13). The level of exposures and vulnerabilities remains very high (Sampebgo, Zan, et al., 2024, p. 17; Sampebgo, Zoundi, et al., 2024, p. 13). The analysis methodology is based on three parts. The objective is to analyze the effects of extreme variations in climatic parameters on the evolution of physico-chemical parameters of soils from irrigation schemes. The samples were analyzed by the laboratory of the National Soil Office (BUNASOLS). The results indicate that climate change influences the three (0.3) fraction texture, carbon, organic matter and exchangeable bases of irrigated soils. To guarantee food security and strengthen the economy of States, it is crucial to put in place effective strategies and techniques for adapting to the climatic risks of irrigation developments in Africa.

Climate change is a universal phenomenon that presents challenges for sustainable development in general throughout the world. Experts agree on the close links between climate change and sustainable development issues (DAB, 2012, p. 05; FERDI et al., 2018, p. 18; IPCC, 2014, p. 66; Nectar et al., 2012, p. 81) . Since the 1980s, the global temperature of each decade has been higher than all those that preceded it since the reference pre-industrial period 1850-1900 (1°C). The special report on the impacts of global warming of 1.5 °C of the Intergovernmental Panel on Climate Change (IPCC, 2022, p. 07) concludes that by 2017, anthropogenic warming had reached about 1 °C above pre-industrial levels, an increase of 0.2 °C per decade. Updated data for 2019 confirm continued warming of 0.1 to 0.3 °C per decade. The year 2016, which began with an El Niño episode of exceptional intensity, remains the hottest year on record with very significant geographical impacts. We can therefore ask ourselves what are the effects of extreme variations in climate parameters on the physicochemical parameters of irrigation schemes?

The objective of this study is to assess the reaction of soils to climatic hazards. It allows a better assessment of the exposures and vulnerabilities of irrigation developments to climatic hazards. In other words, the pedological study allows to assess the sensitivity of the development system to climate change.

2. Materials and methods

2.1 Presentation of the study area

The Nariarlé watershed is located at latitude 12°12'54.03" North and longitude 1°19'46.57" West of Burkina Faso (Map 1). It is defined as a global and coherent geographical entity for water resource management (Doubs, 2012, p. 06) . The Nariarlé watershed is a sub-basin of the Nakanbé (one of the national basins of Burkina Faso). It is bordered to the east by the

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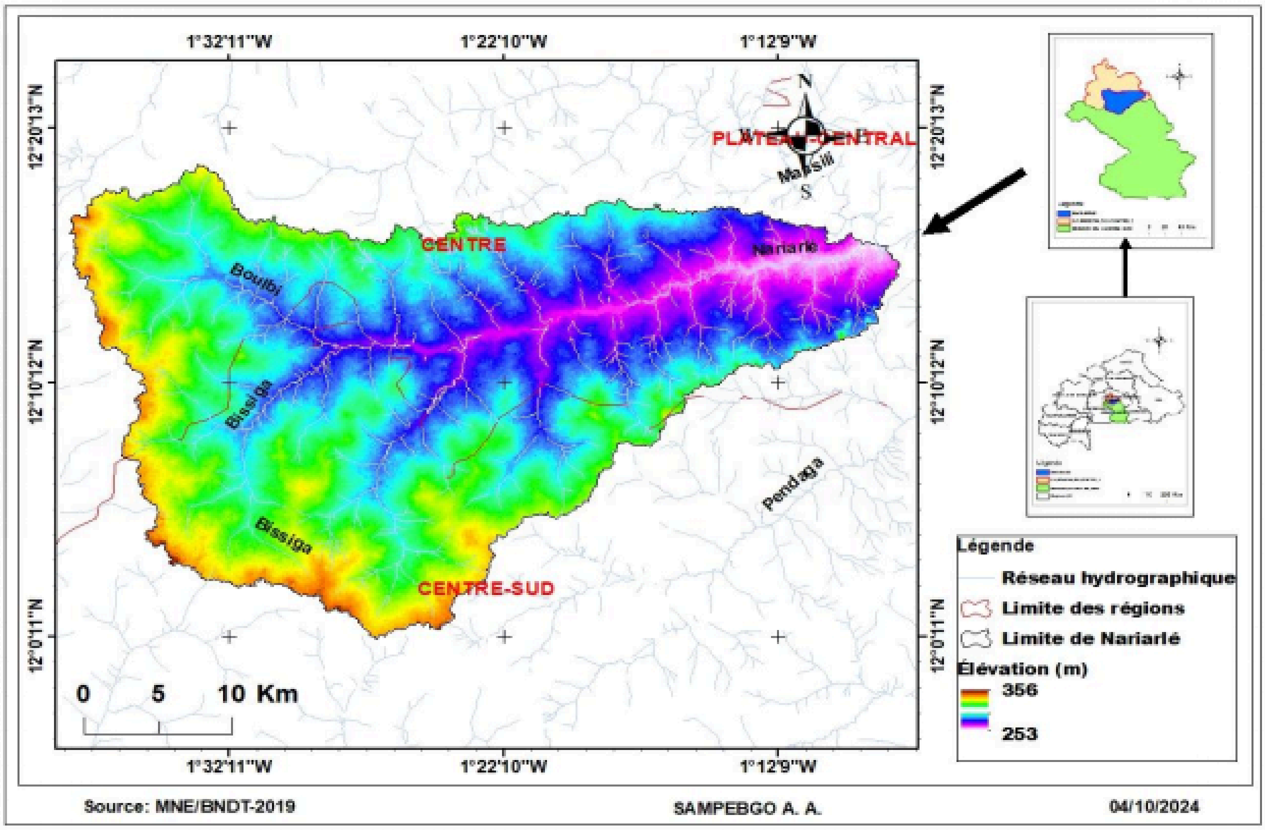
Nakanbé, to the west by the Nazinon, to the north by the Massili and to the south by the Pendjarie. The Nariarlé sub-watershed covers seven (07) municipalities (PCD/Koubri, 2021, p. 18) . Four from the central region (Koubri, Saaba, Komsilga and Ouagadougou) and three from the south-central region, from the province of Bazèga (Saponie, Kombissiri and Boulgou).



Map 1: Geographic location of the study area

2.2. Methodology

The methodological approach adopted to assess the evolution of the physicochemical parameters of the soils of the irrigation facilities of the Nariarlé sub-watershed, Nakanbé in Burkina Faso from 1997 to 2022 is organized around four (04) parts:

- The first consisted of the localization of the geographic coordinates of the profiles ,
- The second section concerned the sampling of localized profiles ,
- The third part consisted of understanding the trends in the employability of phytosanitary products in the watershed from 2022-2024 according to SDAAHM data,
- The fourth is dedicated to analyzing samples.

The number of sampling points selected is eight (08).The coordinates of these sampling points were previously generated using QGIS software and integrated into a GPS, to allow their identification on the ground (Table 1). These coordinates correspond to the profiles of the technical report of the 1997 morphological study of the province at 1 /100,000 (BUNASOLS , 1996, p. 10) . The choice of these coordinates is explained by the desire to provide a more objective response on the consequences of climate change on our sub-watershed by a comparative study of the evolution of the physicochemical components of soils, from 1997 to the present day.

Table 1: Profile coordinates. Source: BUNASOLS

Profiles	X	Y
BZB109	683228.83	1351321.58
BZB111	680327.57	1350700.45
BZB127	686182.22	1342333.3
BZB170	679796.83	1337316.28
BZB210	675193.37	1341582.92
BZB43	659572.19	1349715.94
BZB54	671453.11	1352194.95
BZB85	695499.5	1355149.22

Taking soil samples for laboratory analysis

The number of sampling points selected is 03 (Map 2). The BZB 54 profile, given its location on the national road, we used the geographical coordinates 671 455.886 E and 1352356.792 N_30P, for the collection of the BZB 54 sample. The samples collected were packaged in labeled plastic bags and sent to the laboratory for analysis. The collected soil cores were mixed and homogenized in a plastic bucket, to obtain a composite sample of approximately 500 g. Soil samples were taken at the [0-20] cm and [20-40] cm horizons.

Physicochemical analyses of soil samples in the laboratory

The analysis of the physicochemical parameters of the soils sampled was carried out at the laboratory of the National Soil Bureau (BUNASOLS) according to the methods defined below.

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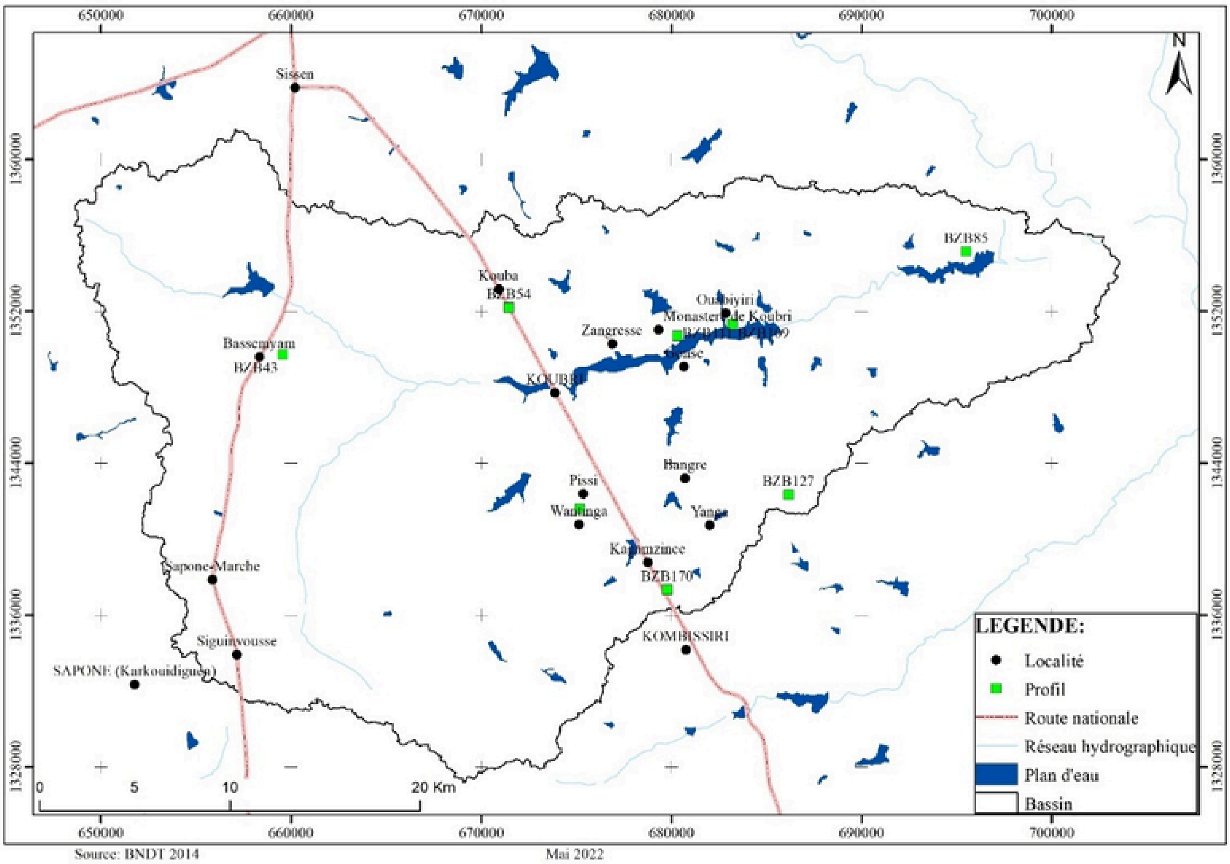

Map 2: Location of profiles

- **Total organic carbon and organic matter.** · Total organic carbon was determined by the Walkley and Black method (1934). Cold oxidation of the soil sample with a potassium dichromate solution (K2Cr2O7), in the presence of sulfuric acid, was followed by a colorimetric determination of Cr3+. The organic matter content was estimated by applying a multiplying coefficient of 1.724 to the determined total organic carbon content: OM (%) = total organic C (%) x 1.724 In fact, it is assumed that the carbon content in organic matter is 58%.
- **Exchangeable bases.** · Exchangeable cations were displaced from the adsorbent complex by a solution of silver nitrate (AgNO3) and thiourea (H2NCSNH2). The cations Ca2+ and Mg2+ were determined using the atomic absorption spectrometer, then Na+ and K+ by flame emission.
- **Water pH.** · The measurements were made by the electrometric method using a pH meter with a glass electrode and direct reading. The solution used for reading is prepared in the earth/water ratio equal to 1/2.5.

The data from the analyses were interpreted and presented in the table below according to the international standards of FAO (1976) adapted by BUNASOLS to the agro-ecological conditions of Burkina Faso and contained in technical documentation No. 6, "Manual for land evaluation" (BUNASOLS, 1990). The assessment of the reaction of the watershed soils to climate change was done by a comparative study of the data from the first technical report of the morphological study of the province of BAZEGA, scale 1 / 100,000 (1982, law No.

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Table :2 The Director of the Analysis Laboratory

Laboratory No.	700	701	702	703	703	705
Original No.	BZB54	BZB 54	BZB 109	BZB 109	BZB 127	BZB 127
Depth	0-20	20-40	0-20	20-40	0-20	20-40
TEXTURE 3 Fractions	LS	LAS	L	L	LS	LAS
Clay %	13.73	27.45	17.65	25.49	15.69	21.57
Total lemons %	19.6	17.65	35.29	31.37	31.37	23.53
Total sands %	66.67	54.9	47.06	43.14	52.94	54.9
CARBON AND ORGANIC						
Total Organic Matter %	1,800	1,245	0.847	0.707	1,645	0.8
Total carbon %	1,044	0.722	0.491	0.41	0.954	0.464
EXCHANGEABLE BASES meq/100g						
Calcium (Ca2+)	4.25	2.76	1.67	2.35	1.63	1.84
Magnesium (Mg2+)	0.33	0.52	0.46	1.18	0.74	0.88
Potassium (K+)	0.15	0.12	0.07	0.29	0.12	0.19
Sodium (Na+)	0.05	0.05	0.05	0.05	0.05	0.07
Sum of bases (S)	4.78	3.45	2.25	3.87	2.54	2.98
Exchange capacity (T) meq/100g	5.94	5.22	4.31	6	5	5.65
Saturation rate (S/T) %	80	66	52	65	51	53
SOIL REACTION						
pH (P/V: 1/2.5)	7.62	7.21	4.5	4.46	5.3	5.23

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0I0/96/ADP of April 24, 1996), modifying the provincial boundaries which establishes its attachment to the province of Kadiogo and erected into a rural commune according to the new legal framework of decentralization called "General Code of Territorial Communities" (December 21, 2004). It was developed as part of the master plan for soil mapping of the current territory of Burkina Faso.

3. Results

The comparative study of the evolution of the physicochemical parameters of soils reveals the following results Table 3.

- · the texture three (03) fractions of the Nariarlé watershed (clay, silt, sand), shows a decrease in the rate of clay, silt and a slight increase in the rate of sand. These losses are explained by anthropogenic and meteorological factors. Erosion (wind or water, anthropogenic) , intensive agricultural practices (excessive use of plowing, excessive drainage, unsuitable management, certain monocultures) of irrigated land, the phenomena of deforestation and land degradation, extreme weather events (heavy rain, strong winds, etc.) disrupt the processes of particle formation and stabilization (clay, silt, sand). They influence the dynamics of particles, their leaching and the decrease in their rate.
- matter has decreased by -4.36% for BZB 127, a significant increase of +16.02 % for BZB 54 and an average of + 6.5% for the BZB 109 profile. These parameters remain relatively high at the level of the profiles located in the irrigated areas. This is explained by the intensive use of mineral fertilizers (Urea, NPK) and organic fertilizers (organic manure) on the crop plots.
- · The carbon rate remains high overall. In 25 years it has gone from 1.25% to 18.17% for the BZB 54. That is an increase of +16.92 %. From 13.55% for the BZB 109 profile in 1997 the carbon rate has gone to 19.10% in 2022 (i.e. +5.55%).

The increase in carbon content is explained by the factors of decomposition, oxidation or sequestration of organic carbon contained in the soil. The intensive application of fertilizers and pesticides (by the decomposition process), drainage (by the oxidation process), the supply of organic residues from biomass, extreme weather events contribute to increasing CO_2 emissions and other greenhouse gases in the soil. Extreme temperatures accelerate the decomposition of organic matter and release soil carbon into the atmosphere . Heavy rainfall events such as flooding cause losses of organic carbon in soils and alter greenhouse gas fluxes.

- Bases are experiencing a very significant increase in irrigation schemes. In 25 years, the potassium (K+) content in the soil has increased from +18.85 at the BZB 54 profile, +6.11 for BZB 109 and +2.32 for BZB 127. The amount of sodium (Na+) is experiencing a decrease overall (-2.66 BZB 109; -5.91 BZB 127).
- PH is increasing, waters are becoming more basic. Agricultural chemicals such as fertilizers contain basic components (ammonia) that cause an increase in water pH. Interactions between extreme variations in climatic parameters and land degradation affect various ecosystem functions and have a significant impact on food production, livelihoods and human well-being (UNCCD, 2015, p. 03) .

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Table 3: Evolution of physicochemical parameters of soils from 1997 to 2022. BUNASOL, 2022

Laboratory No.						
Original No.	BZB 54	BZB 54	BZB 109	BZB 109	BZB 127	BZB 127
Depth	1997	2022	1997	2022	1997	2022
TEXTURE 3 Fractions						
Clay %	9.8	23.33	22.1	21.81	27.77	21.57
Total lemons %	15.69	19.47	15.78	19.41	20.97	18.57
Total sands %	74.51	19.03	14.29	19.56	19.63	20.18
CARBON AND ORGANIC MATTER						
Total Organic Matter % (OM)	2.15	18.17	12.54	19.09	20.9	16.54
Total carbon %	1.25	18.17	13.55	19.1	20.89	10.48
EXCHANGEABLE BASES meq/100g						
Calcium (Ca2+)	1.85	17.87	16.9	21.69	22.26	20.6
Magnesium (Mg2+)	0.38	22.23	18.87	24.39	24.16	20.86
Potassium (K+)	0.03	18.88	12.85	26.11	19.93	22.25
Sodium (Na+)	0.01	20	22.66	20	27.57	21.66
Sum of bases (S)	2.26	18.38	17.19	22.65	22.99	20.79
Exchange capacity (T) meq/100g	2.42	19.35	18.43	21.64	23.52	20.61
Saturation rate (S/T) %	94	19	16	21	22	20
SOIL REACTION						
pH water (P/V: 1/2.5)	7	19.72	16.9	19.96	22.34	19.93

Phytosanitary products represent chemical or biological substances or mixtures, used against pests (insecticides, fungicides, etc.), against weeds (herbicides), as products regulating plant growth, the quality of harvests and reducing yield losses.

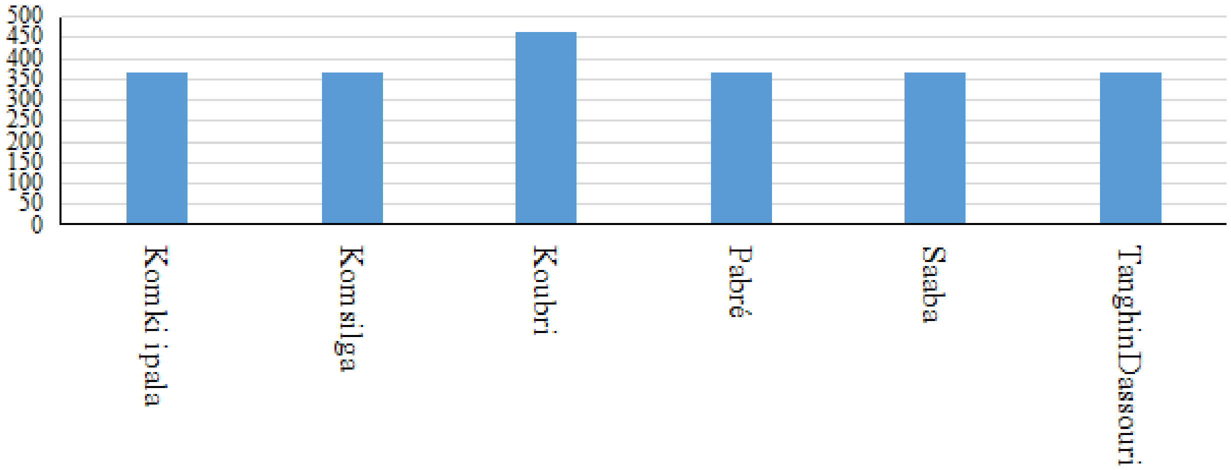

Figure 1: Municipal distribution of phytosanitary products (2024). Source: SDAAHM / 2024

The analysis of the distribution of phytosanitary products in rural municipalities in the region in 2024 shows a strong distribution of phytosanitary products in the commune of Koubri compared to the five other communes, which are the communes of Saaba, Pabré, Tanghin Dassouri, Komki-Ipala and Komsilga (Figure 1).

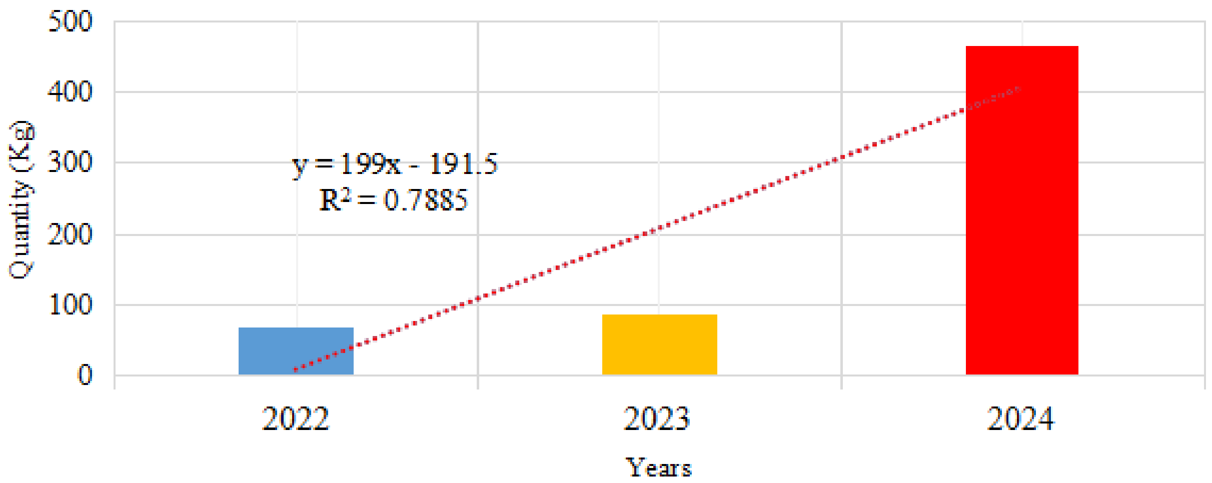

Figure 2: Inter-annual evolution of the use of phytosanitary products in the commune of Koubri. Source: SDAAHM / 2024

Figure 2 indicates that phytosanitary products are increasingly used in hydro-agricultural developments in Koubri with an increase of +85.25% from the period 2022 to 2024. The analysis of the types of applied plant protection products indicates different varieties of products (Figure 3). The availability of products depends on the initial stock or allocation. The insufficiency of these allocated products is conditioned by their supply in local markets by producers.

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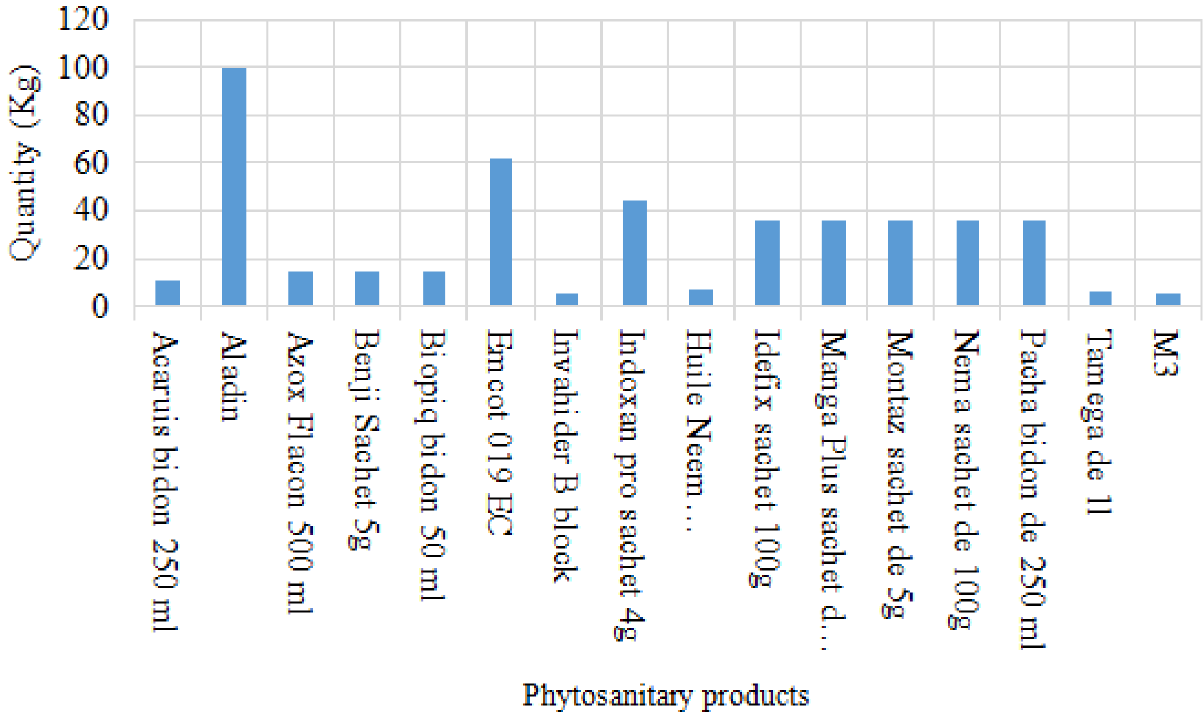

Figure 3: Distribution of phytosanitary products in the municipality of Koubri 2024. Source: SDAAHM / 2024

The phytosanitary products of the Aladin brand, Emacot 019 EC (contains emamectin benzoate), Indoxacarb and Pacha products are the most used in hydro-agricultural developments in 2024, intended to protect various agricultural crops (Figure 3).

4. Discussion

Irrigation systems are confronted with extreme variations in climatic parameters. These climatic variations affect the physicochemical components of soils. Irrigation systems are increasingly confronted with the problems of silting and impoverishment of clay soils (Tahirou et al., 2022, p. 09) . According to Gérald et al. (2011, p. 07) , humus "protects" clay and stabilizes the soil structure through the clay-humus bond and through Ca^{2+} cations . This reinforces the stability of aggregates to water erosion. Analysis of the physicochemical parameters of irrigation systems reveals an increase in the amount of carbon in the soil. A high amount of carbon in the soil can have several consequences on irrigation systems. First of all, carbon can affect the structure of the soil by making it more compact and less permeable to water. This can lead to water flow problems, which can cause flooding or areas of stagnant water. In addition, carbon can also influence the soil's ability to retain water and nutrients. High carbon can lead to increased soil acidity, which can affect the availability of nutrients to plants. Finally, carbon also promotes the development of certain soil diseases, such as root rot. However, it should be noted that soil carbon can be organic, i.e. a constituent of soil organic matter, but it can also exist in mineral form ("inorganic carbon") (Bernoux et al., 2013, p. 09) .

The potassium ($K+$) content in the soil, the amount of sodium ($Na+$) is experiencing a slight decrease in the developments. Sodium is one of the most undesirable elements in irrigation water. It influences soil permeability and water infiltration (Couture & Montérégie-Est, 2004, p. 02; Ramdani Abir, 2022, p. 20) . Minerals such as sodium and potassium can play an important role in irrigation developments in Africa. Their presence in irrigation waters in Africa may be due to soil salinization, excessive use of fertilizers, decomposition of organic matter rich in sodium or potassium or natural processes such as soil erosion. The decrease in the amount of potassium in irrigation developments can have several consequences on plants. Potassium is an essential element for many physiological functions in plants, including regulation of stomatal opening and closing, root growth, and disease resistance. Potassium deficiency can result in symptoms such as yellowing leaves, brown leaf margins and spots, stunted growth, and increased susceptibility to diseases and environmental stresses. For example, in potato crops, potassium deficiency can result in reduced yield and tuber quality, as well as post-harvest storage problems. When it comes to decreasing the amount of sodium in irrigation systems, this can also have consequences for plants. Sodium can be toxic to many plants if it is present in excess in the soil. An increase in sodium in the soil can lead to a decrease in the uptake of essential nutrients by plants, disruption of the water balance of plants and damage to the roots. Therefore, it is important to monitor and maintain an adequate balance of potassium and sodium in irrigation systems to ensure healthy and optimal plant growth.

Increasing the amount of magnesium ($Mg2+$) and calcium ($Ca2+$) in irrigation systems can also impact plants. First, increased magnesium can lead to competition with other cations, such as potassium and calcium, for plant uptake. This can lead to potassium and calcium deficiencies, which can affect plant growth and development. In addition, excess magnesium can also cause soil alkalinity, which can affect plant nutrient uptake and lead to toxicity issues for some sensitive crops.

When it comes to calcium, increasing its amount in the soil can have positive effects on plants, as calcium is essential for cell wall formation, root growth, and disease resistance. However, excess calcium can also lead to problems, such as impaired absorption of other nutrients, nutritional imbalances, and soil salinity problems.

5. Conclusion

The analysis of the physicochemical parameters of the soils of the Nariarlé hydro-agricultural developments reveals that climate change influences the irrigation activities of the developments. They cause water erosion of the soils and excessive use of fertilizers in the irrigated areas. The modification and intensification of cultivation practices and techniques lead to an increase in the quantity of magnesium ($Mg2+$) and calcium ($Ca2+$). The potassium ($K+$) content in the soil and the quantity of sodium ($Na+$) are experiencing a slight decrease. Carbon is increasingly stored by irrigation developments. The quantity of organic matter remains relatively high at the level of the profiles located in the irrigated areas . Thus, in 25 years, irrigation developments have significantly suffered from the effects of climate change.

As a result, effective adaptation practices and techniques must be adopted for the sustainable development of irrigated agriculture in Africa.

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