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Climate Risks of Irrigation Developments in the Nariarle Sub- watershed in Koubri, Nankanbé Basin, Burkina Faso

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Authors' contributions

This work was carried out in collaboration among all authors. Author SAA designed the study, carried out the statistical analyses, produced the maps, wrote the protocol and the first draft of the manuscript. Authors OI and BJ managed the analysis. All authors read and approved the final manuscript.

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ABSTRACT

Irrigation schemes in the Nariarlé sub-watershed, Nankanbé basin in Burkina Faso are exposed to climatic risks. These risks are accentuated by the combination of several natural, biophysical and anthropogenic factors. The objective of this study is to assess the climate risks of developments in Burkina Faso. The absence of a previous study assessing the risks of the basin highlights the

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originality of this article. Documentary research and the processing of satellite images served as methodology. This methodology is supported by field surveys of 160 farmers, questionnaires and interview guides. The climatic analysis shows an evolution of minimum and maximum temperatures and a persistence of deficit years. The climate risks identified are: risks of vulnerability to climatic hazards (water stress, soil erodibility, flooding of irrigated areas, heatwaves), risks of exposure (demographic pressure, increase in the level of $CO_{2\ content}$ of developments, economic deficit). Climate risk assessment provides decision support tools, guidance, effective adaptation practices and techniques.

Keywords: Burkina Faso; climate risks; irrigation; watershed.

1. INTRODUCTION

Climate change is a universal phenomenon, no country is spared, from the richest to the poorest. Its consequences are multiple and affect all areas of human and state life [1, p. 03], [2, p. 11]. From the melting of glaciers and ice in Greenland, to climate disorganization, including increased warming of the oceans, prolonged droughts, associated with forest fires of unprecedented scale as in the case of Australia (2019, 2 020), Siberia, 2019, 2023). In the opinion of several authors, climate change constitutes the greatest fundamental challenge of the 21st century [3, p. 10], [4, p. 03], [5, p. 10] . The year 2019 ended with an average global temperature 1.1°C higher than the pre-industrial averages of 0.1°C from 1850-1900 [6, p. 05] . More ambitious efforts need to be made in the area of mitigation and to keep temperature rises below 2°C by the end of the century [7, p. 05], [8, p. 02], [9, p. 01] . The fight against climate change and its effects is everyone's business according to UN Secretary General Guterres A. [10, p. 06]. Margined, the ratifications of the various international conventions and protocols to combat climate change [11, p. 12], [12, p. 12], [13, p. 03], [14, p. 02], [15, p. 07], [16, p. 03] , multiple national sustainable development strategies implemented [17, p. 10], [18, p. 15], [19, p. 10], [20, p. 10] , Burkina Faso, like many African countries, remains extremely exposed to the risks linked to climate change [10, p. 04], [17, p. 36], [21, p. 41] . Due to climate risks, irrigated areas in Burkina Faso overall have an unbalanced water regime in relation to water needs [22, p. 16] , poor economic performance [23, p. 11] , low irrigable areas with a strong increase in the density of producers [24, p. 03] . Practices and techniques for adapting to extreme climates are weak. Pest attacks and flooding of perimeters are becoming more and more frequent [25, p. 21] . The orientation towards the use of groundwater resources, major development policies [18, p. 09], [23, p. 17] ; management and sustainable use of water resources [26, p. 18], adaptation to climate change [27, p. 04] are all challenges that irrigation developments in Burkina Faso face. Studying the risks linked to climate change from irrigation developments is an opportunity to assess climate risks and develop effective adaptation strategies. Irrigation developments are one of the alternatives to deal with climate change, food insecurity and the diversification of production.

2. MATERIALS AND METHODS

2.1 Presentation of the Study Area

The Nariarlé watershed is located between latitude 12°12'54.03" north and 1°19'46.57" west of Burkina Faso (Map 1). It is defined as a global and coherent geographical entity for water resource management [28, p. 06] . The Nariarlé watershed is a sub-basin of the Nakanbé (one of the national basins of Burkina Faso). It covers seven (07) municipalities [29, p. 18] : four from the central region (Koubri, Saaba, Komsilga and Ouagadougou) and three from the south-central region, Bazèga province (Saponi, Kombissiri and Boulgou).

The irrigated areas are organized around the four sub-basins which are the areas of Wédbila, Koubri, Monastère and Nabazana (Map 2).

Boussouma irrigation schemes are located at 1°17'40.2" East, 12°12'55.2" North, 170 km from Ouagadougou. The Boussouma watershed (Map 3) covers an area of 3.3 km^2 with an average slope of 0.01 according to technical studies. The hydrological balance deduced by analogy with the results of ORSTOM [30, p. 50) indicated a maximum specific flow of 11.40 $m^3/s/km^2$, i.e. a maximum flood of 38m ^{3}/s (Q= 3.3* 11.40) [31, p. 26] .

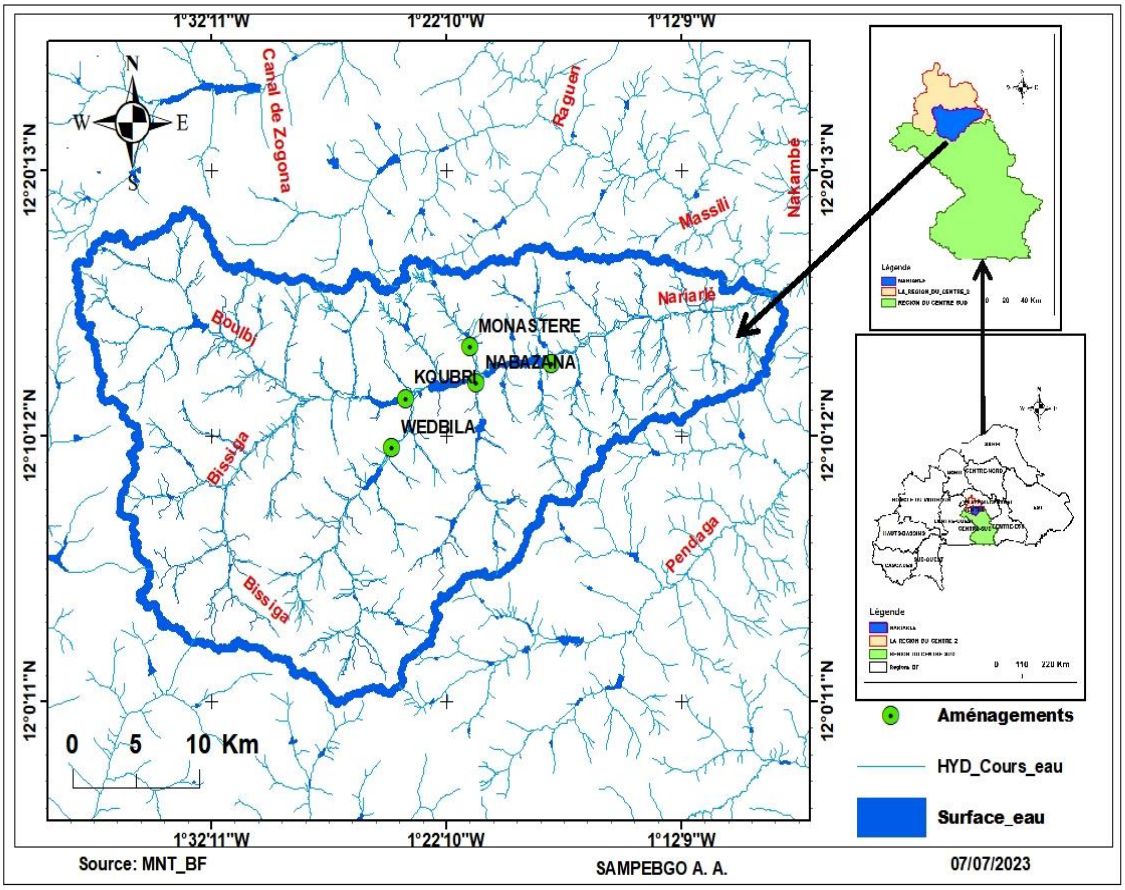
Nabazana irrigation scheme is located at altitude 12°12'10.8" north and longitude 1°20'52.2" east. It has for an altitude between 270 m and 356 m developed and put into operation in 1974, the basin (Map 4) records 20 ha of developed area and a dam with a capacity of 380,000 m 3 of water.

The developments of Koubri II. Financed by the Canadian fund (85,300,000 CFA), the Koubri II developments are located 674320.871 East and 1348480.929 North. Its altitude is between 273 m and 356 m (Map 5). It is located in the village of Tanvi in the commune of Koubri, approximately 30km from Ouaga. Made in 1976 [32, p. 03] , rehabilitated in 1986, the Koubri dam is characterized by:

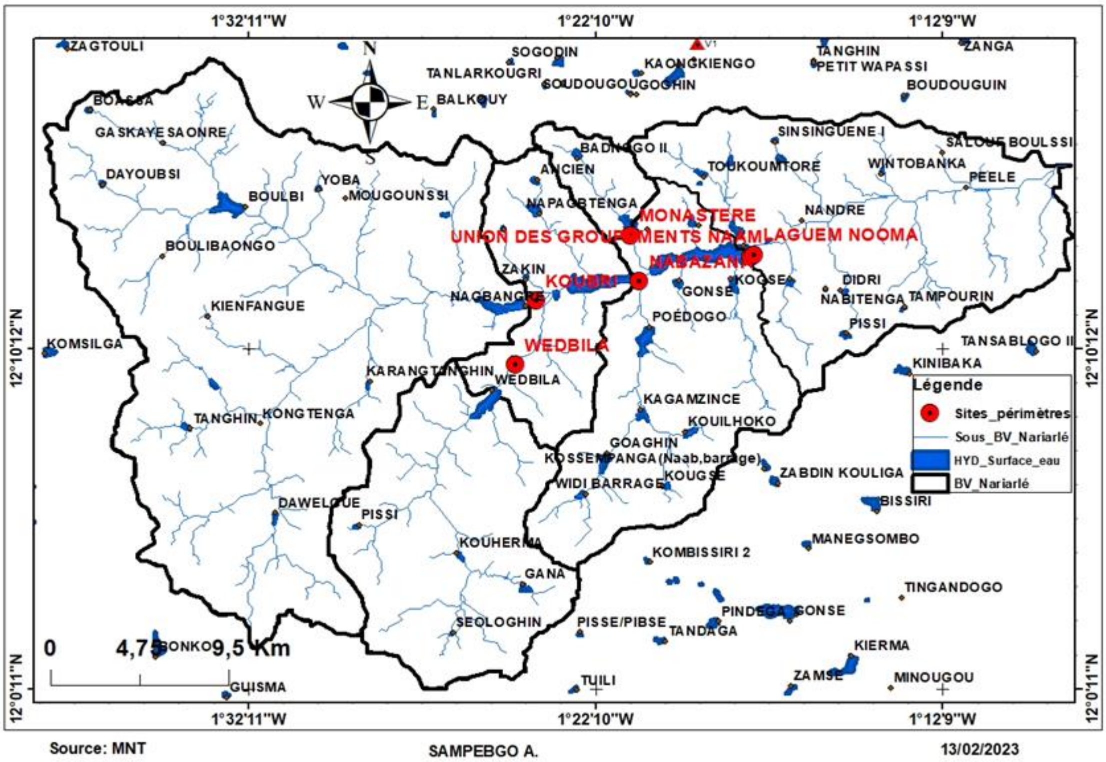
- A water retention dike three meters (3m) high and 360 m long
- A homogeneous dam (capacity 1960000m ^{3,} flow 2300000 m ^{3}/s,)
- A central spillway
- Two intake structures (upstream valve, right bank; downstream valve, left bank) Volume of water stored 670,000 m ^{3} (water availability April-May).

The Monastery's developments (Map 6) are organized over a 15ha irrigated area of gravity type. Water is taken by valve or by pumping, developed and made available to producers in 1989. Its geographical coordinates are 12°13'33.2" North latitude and 1°21'08.9" East longitude. Sold in 2018, the level of degradation of the dam remains average. It is located from 277m to 323m above sea level.

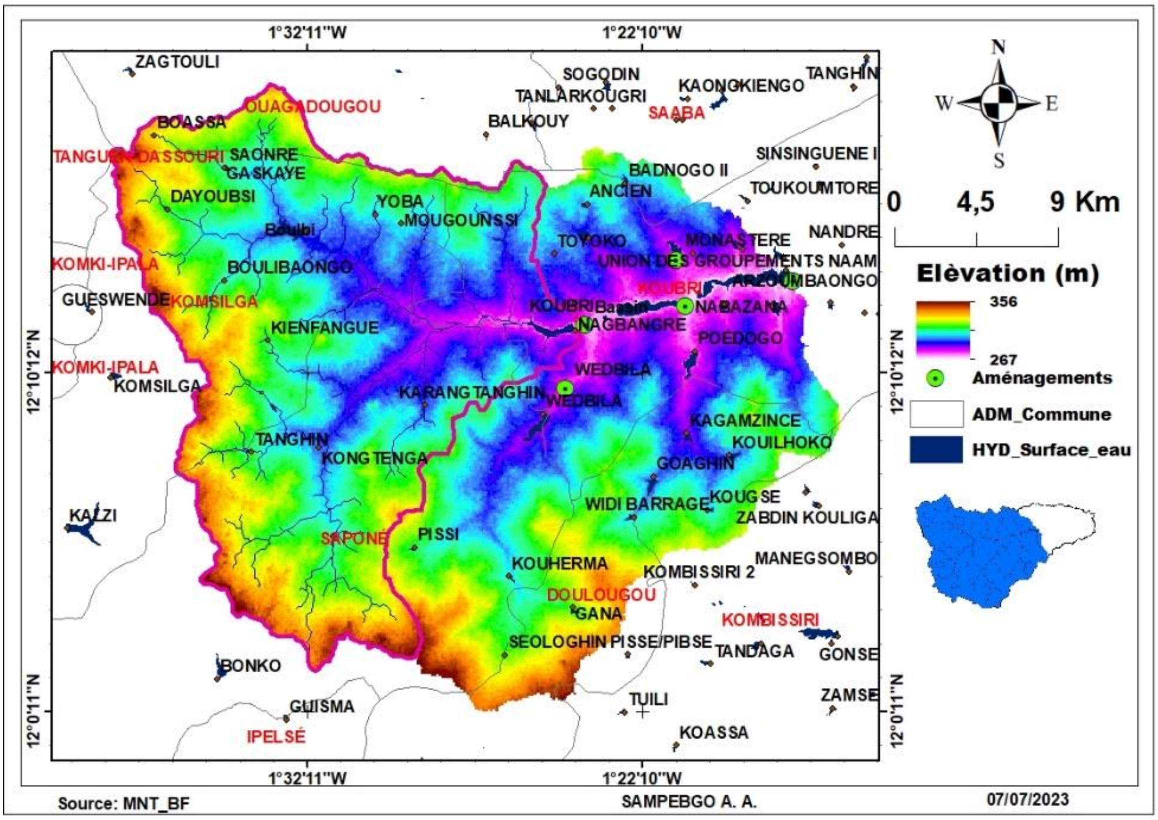
The Wèdbila dam was built in 1979 by the Oumarou KANAZOE company. Located southwest of the village Wèdbila (673262.07E, 1345008.523N) approximately 40 km from Ouaga, it was renovated at an estimated cost of 158,000,000 FCFA with a ten-year flood estimated at 65 m3/s. its flow rate is estimated at 2,480,000 m ^{3} /s. It is located between 280 m and 354 m above sea level and has 74 tributaries. An area of 148.6 km2, 58.95 km perimeter.



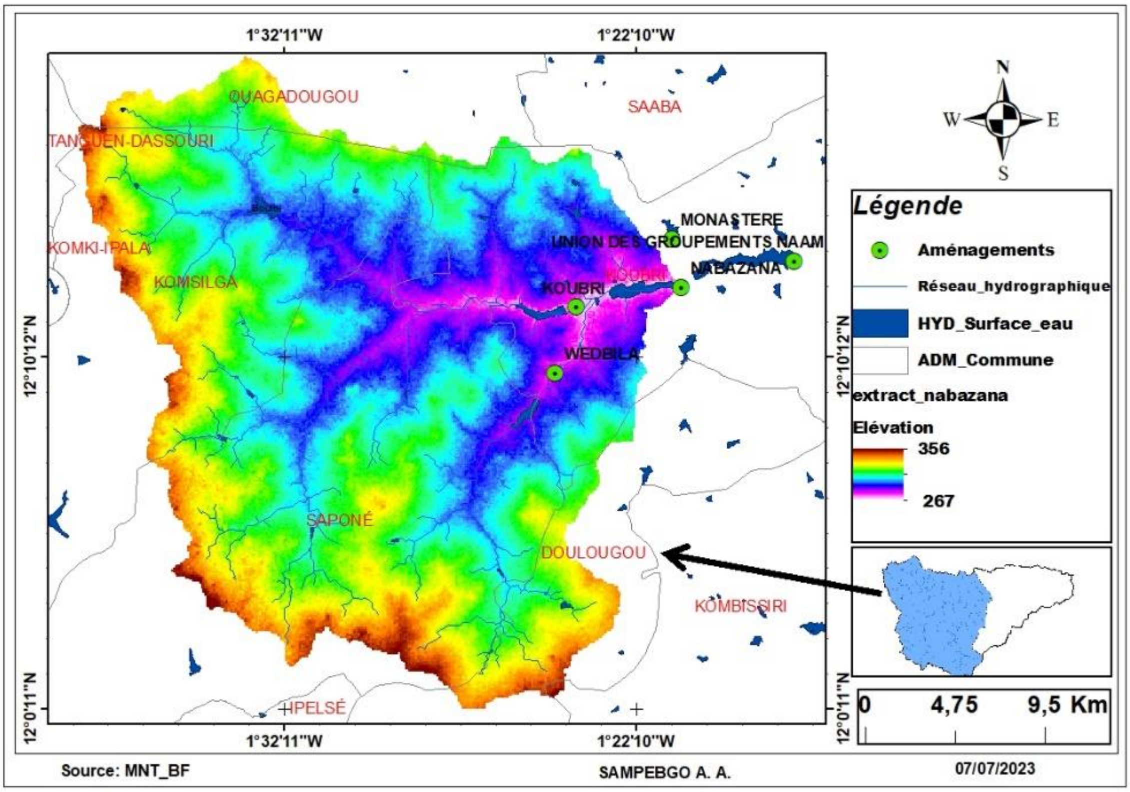
Map 1. Location of the nariarle sub-watershed



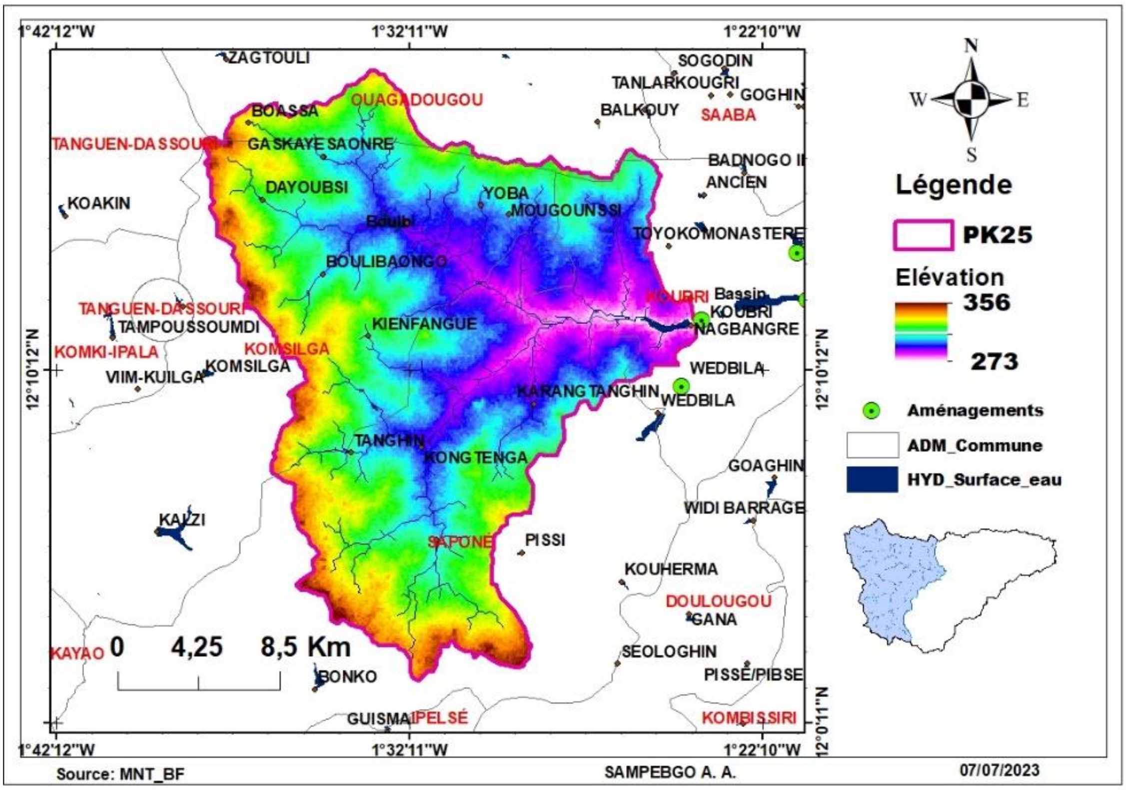
Map 2. Irrigation schemes in the nariarle watershed



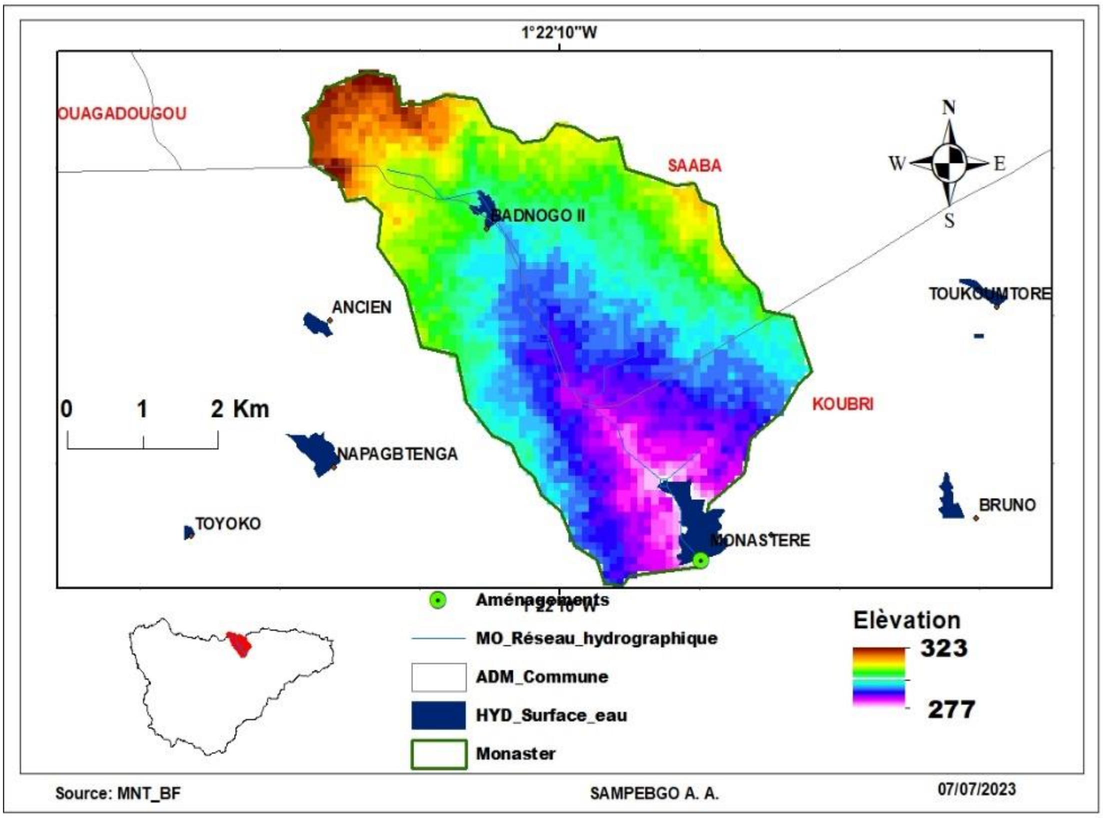
Map 3. Boussouma irrigation management



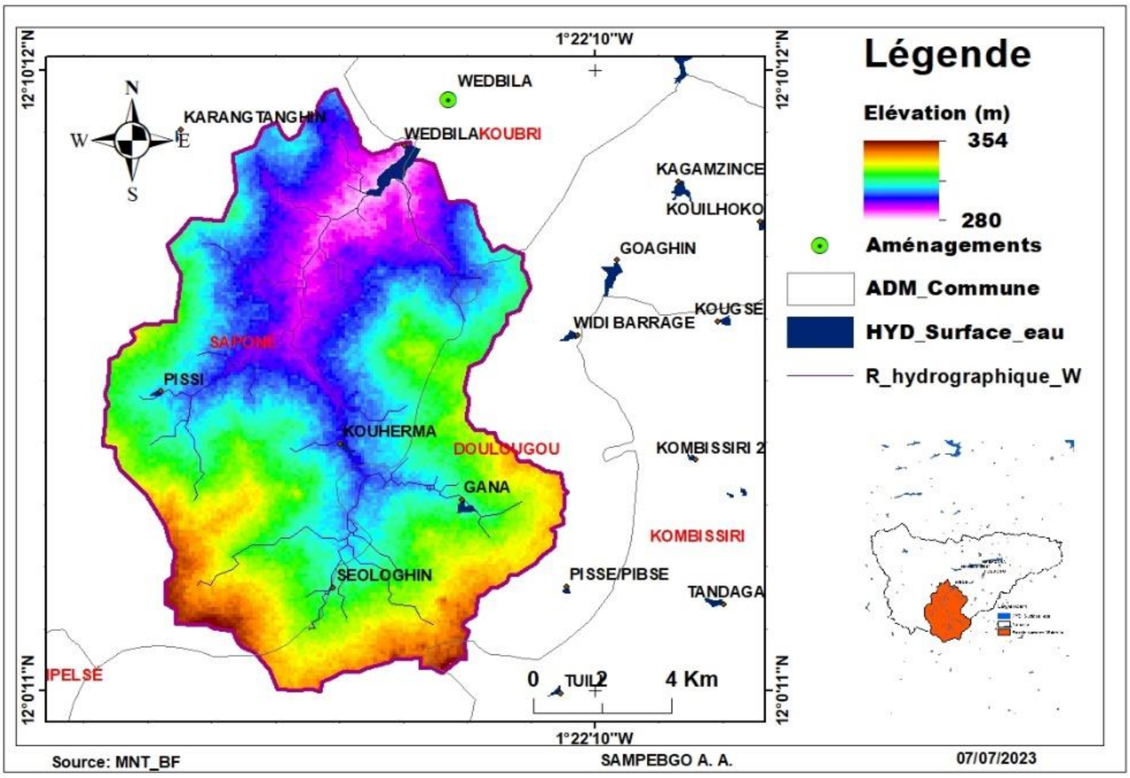
Map 4. Nabazana irrigation management



Map 5. The irrigation facilities of Koubri II



Map 6. The arrangements of the monastery



Map 7. Wédbila developments

2.2 Methodology

To assess the risks linked to climate change from irrigation developments in the Nariarlé watershed, the structure of an impact chain developed according to the IPCC Assessment Report 5 (AR5) approach was used. It makes it possible to analyze, systematize, better understand and prioritize the factors responsible for risks and its components (Fig. 1). These techniques are based on empirical observations, statistical approaches, descriptive models and the well-founded knowledge of stakeholders on climate risks (IGB, 2015).

The structure is organized around three (03) approaches according to the specific objectives of the study: climatic hazards, exposures and vulnerabilities. These approaches are evaluated as follows:

- The climate or climate hazards approach aims to identify and map the determining factors of climate risks. The map of climatic hazards is obtained by superimposing the map of maximum daily temperatures and that of maximum daily precipitation using the " *weighted arithmetic aggregation* " method (Eq.1), recommended and described by the GIZ [33, p. 130], [34, p. 52], [35, p. 128] . The maximum daily temperatures and precipitation for irrigation schemes are obtained by interpolating the maximum temperatures and precipitation from the CORDEX project for the year 2022 (RCP 8.5). The spatial analysis points correspond to the coordinates of the irrigation schemes of the different watersheds of Nariarlé (Table 1).

$$Tn_{i,0/1} = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad \text{(Eq. 1)}$$

$$IC = \frac{(I_1 \times W_1 + I_2 \times W_2 + I_3 \times W_3)}{\sum_1^n W} \quad \text{(Eq. 2)}$$

IC: composite indicator . W: is the coefficient assigned to the indicator.

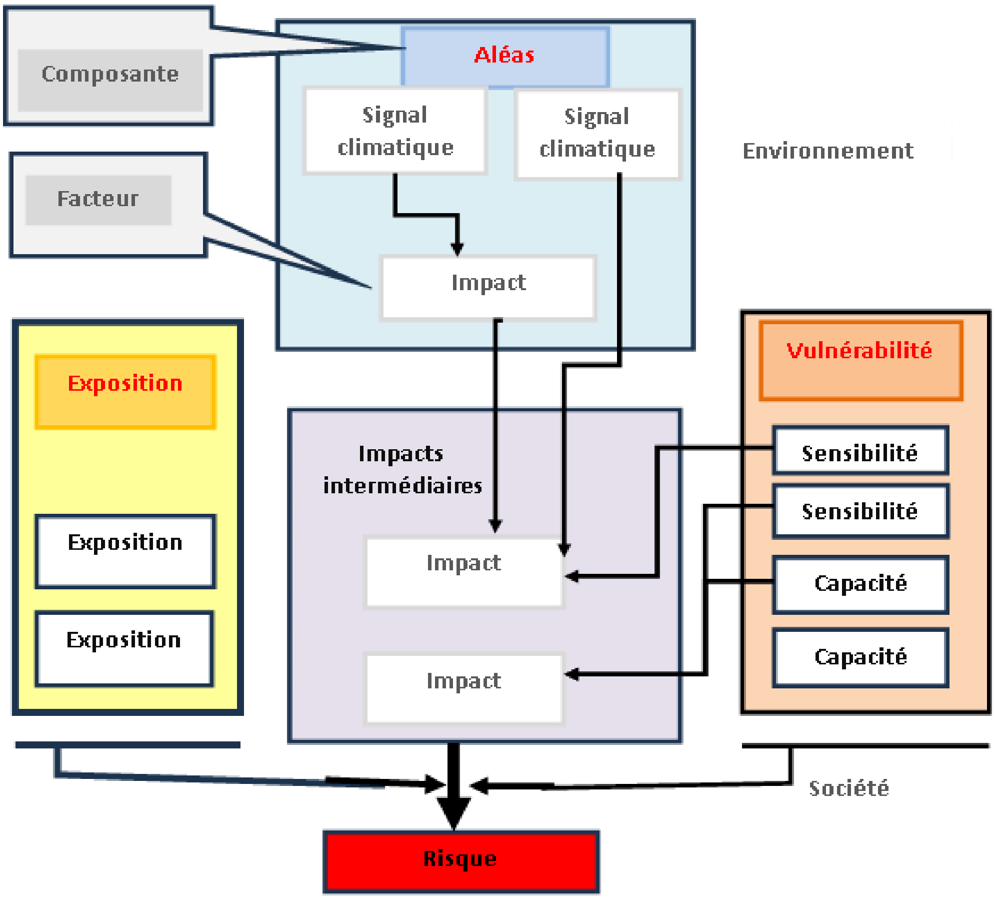


Fig. 1. Structure of an impact chain according to the IPCC AR5 approach

Table 1. Weighted arithmetic aggregation of climatic hazards

Extraction points	Latitude	Longitude	Tmax (°C)	Pmax (mm)	Normalized values			Level of hazards
					Tmax (°C)	Pmax (mm)	IC	
V1	12.32	-1.32	46,103	65.46				
V2	11.88	-1.32	44,966	60,047				
V3	11.88	-1.76	44,657	112,474				
V4	12.32	-1.76	45,478	106,034				
KOUBRI	12.19363	-1.39769	45.75	98.7	0.6	1	0.8	Very high
WEDBILA	12.1623	-1.40761	45.52	79.5	0	0.38	0.19	Weak
NABAZANA	12.20314	-1.34797	45.63	69	0.28	0.04	0.16	Very weak
MONASTERY	12.22588	-1.35247	45.9	68.5	1	0.02	0.52	Pupil
BOUSSOUMA I	12.2154	-1.29457	45.8	67.7	0.73	0	0, 36	Average

Source: SAMPEBGO A., 2023

Table 2. Level exhibition

Site (s	Social exhibitions	Technology exhibitions	Reverse economic exposures	Exposure aggregations	Level of exposures
Monastery	0.04	0.94	0.42	0.46	Average
Nabazana	0	0.50	0.27	0.25	Very weak
Wédbila	1	0.47	0	0.49	Pupil
Boussouma I	0.31	0.46	0.3	0.36	Weak
Koubri	0.2	0.43	1	0.54	Very high

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- The complementary approach or exposures, used for the identification and analysis of practices and complementary strategies at risk of irrigation developments to climatic hazards. They constitute complementary units for evaluating opportunities or threats to adaptation strategies. They are based on an index system integrating *social, technological and economic indicators* (Table 2). She constitutes a decision-making tool for choice and priority of intervention for more effective management of climate risks.

Exhibitions : correspond to anthropogenic factors such as demographic pressure.

For Technology Exhibitions: The method used is the weighted aggregation of the $CO_{2\ rate}$ on the ground according to the profiles BZB 54 , BZB 109 and BZB 127 and the technological level (the number and types of agricultural tools used on ten (10) developed areas visited).

Economic Exhibitions: They are determined from the economic productivity cost of irrigation developments in millions of FCFA (CP) for the 2021-2022 dry season agricultural campaign of four types of production (tangelo, corn, rice and tomato).

$$\mathrm{CP} = \sum_{n}^{1} \mathrm{Q_i} \times \mathrm{P_i} \quad \text{(Eq.3)}$$

$\mathrm{Q_i} =$ The quantity of products

$\mathrm{P_i} = \mathrm{Prix\ unitaire\ par\ production}$

- The third subsection is based on **the vulnerabilities** which are organized into two (02) sub-indexes which are (Table 3): vulnerability to erosion (the speed of alteration or friability of the basin, protection of the soil by vegetation) and vulnerabilities to water stress. Values 1-0 are given, 0 being a value for development with very low vulnerability and 1 for very vulnerable development.

The mapping of climate risks for irrigation schemes is illustrated by superimposing the map of hazards, exposures and vulnerabilities (Table 4).

Field Data Collection Strategy: This consists of carrying out surveys with local populations and institutions in the field with a view to completing the digital data. A questionnaire is administered to 150 stakeholders distributed according to the number of operators per irrigation scheme (Table 05). Interview guides (10) are sent to institutional authorities, private structures and planning experts to refine the information collected from the population. As part of our analysis, the indicators used are: categorical indicators (low, moderate, high category); binary indicators (the “yes” or “no” value which can be quantified into “0” and “1”) and continuous indicators, based on measurable quantities including costs. Three (03) variables are used to analyze practices and techniques for adaptation to climate risks of irrigation schemes in the Nariarlé watershed (Prevention or anticipation, reduction or resilience, monitoring-evaluation).

Table 3. Level of vulnerabilities

Site (s	Vulnerabilities		Aggregated value	Level of vulnerabilities
	Erodibility	Stress		
Boussouma 1	0.58	0.89	0.73	Very high
Monastery	0.03	1	0.51	Average
Nabazana	0.59	0.77	0.68	Pupil
Koubri	0.72	0.11	0.41	Weak
Wèdbila	0.57	0	0.28	Very weak

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Table 4. Level of risks

Site (s	Hazards	Exhibitions	Vulnerabilities	Risks	Risk level
Boussouma 1	1	0.36	0.73	0.69	Very high
Monastery	0.75	0.46	0.51	0.57	Pupil
Nabazana	0.50	0.25	0.68	0.46	Average
Koubri	0.27	0.54	0.41	0.39	Weak
Wédbila	0	0.49	0.28	0.25	Very weak

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Table 5. Number of respondents by irrigated areas

Irrigated areas	Number of respondents
NABAZANA	15
WEDBILA	65
PK 25 DOWNSTREAM	25
MONASTERY	15
SOUGRI NOOMA	30

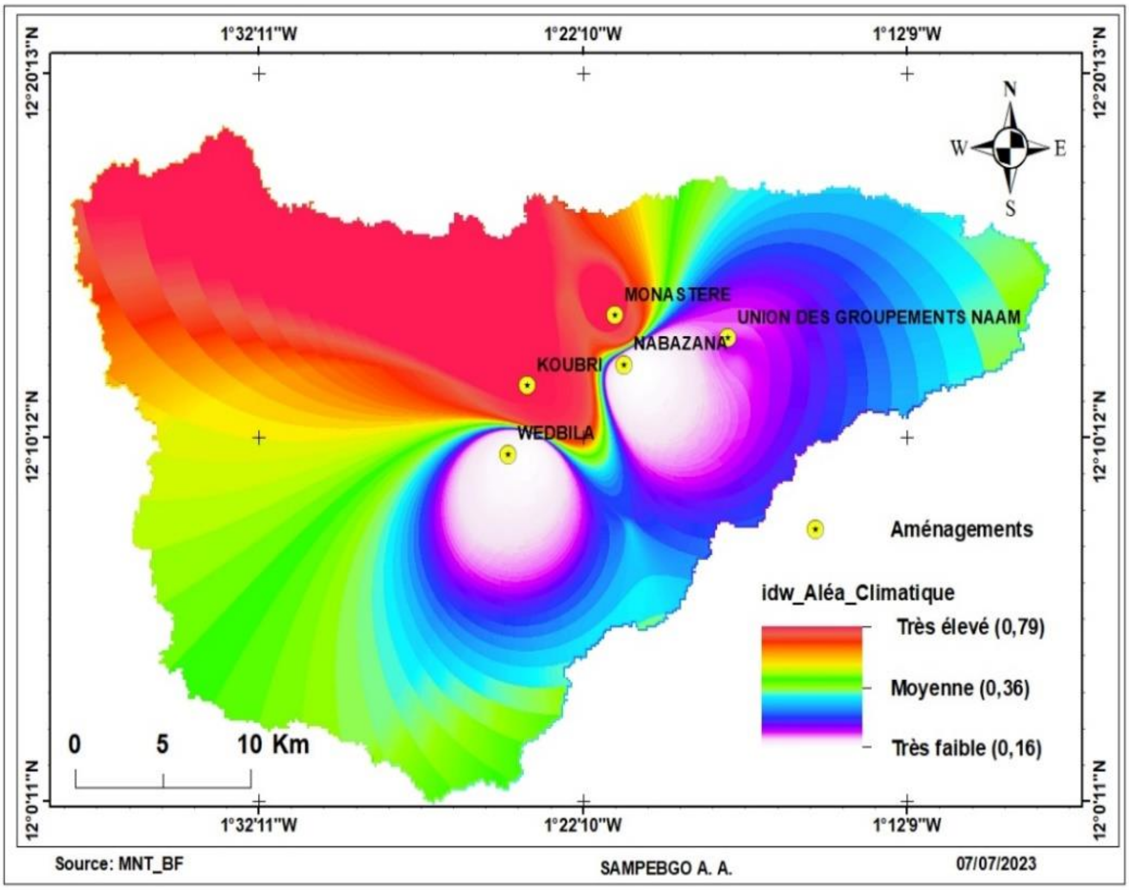
3. RESULTS

3.1 Climatic Hazards

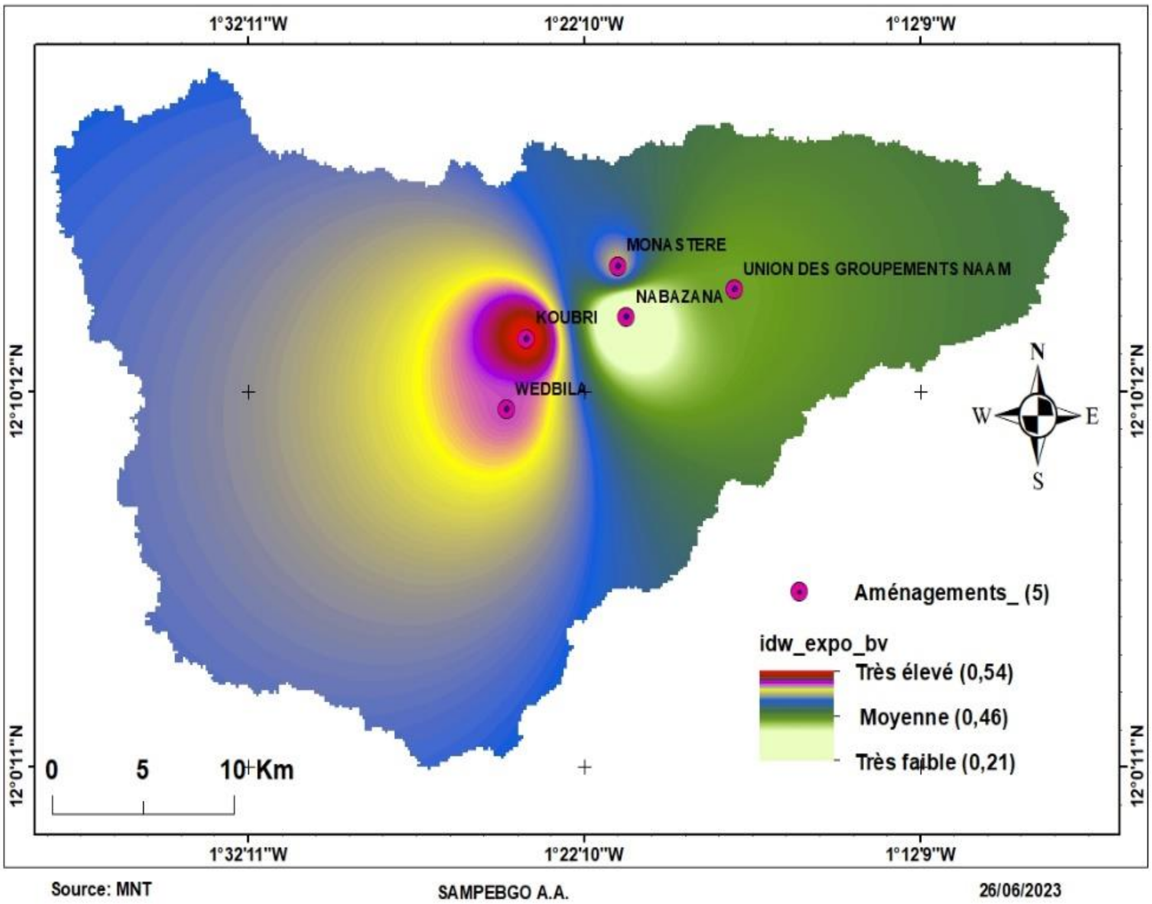
The climate hazard map reveals a very high level for the Koubri developments , high for the Monastery, moderately for Boussouma I, low for the Wédbila development and very low for the irrigated areas of Nabazana (Map 8). These results show that the Koubri developments experience the highest temperatures and flooding of the irrigated areas. The irrigated areas of Nabazana remain very slightly vulnerable.

3.2 The Exhibitions

Exposure mapping reveals that the Koubri developments have very high exposure and those of Nabazana have very low exposure. The Monastery remains moderately exposed (map 9). This implies strong demographic pressure from the Wédbila developments; it will be preferable to increase the irrigable areas of these areas. Technological exposures are high at the Monastery and very low economic efficiency at Koubri. We must therefore focus on financing producers, granting credits and production inputs adapted to climate risks.



Map 8. Hazards climatic



Map 9. Exposure to climatic hazards

The results observed are (Map 10):

- A very high level of vulnerabilities of the Boussouma developments
- A high level of vulnerabilities of Nabazana developments
- An average level of vulnerability of Monastery developments
- A low level of vulnerabilities in Koubri or PK25
- A very low level of vulnerabilities in Wédbila

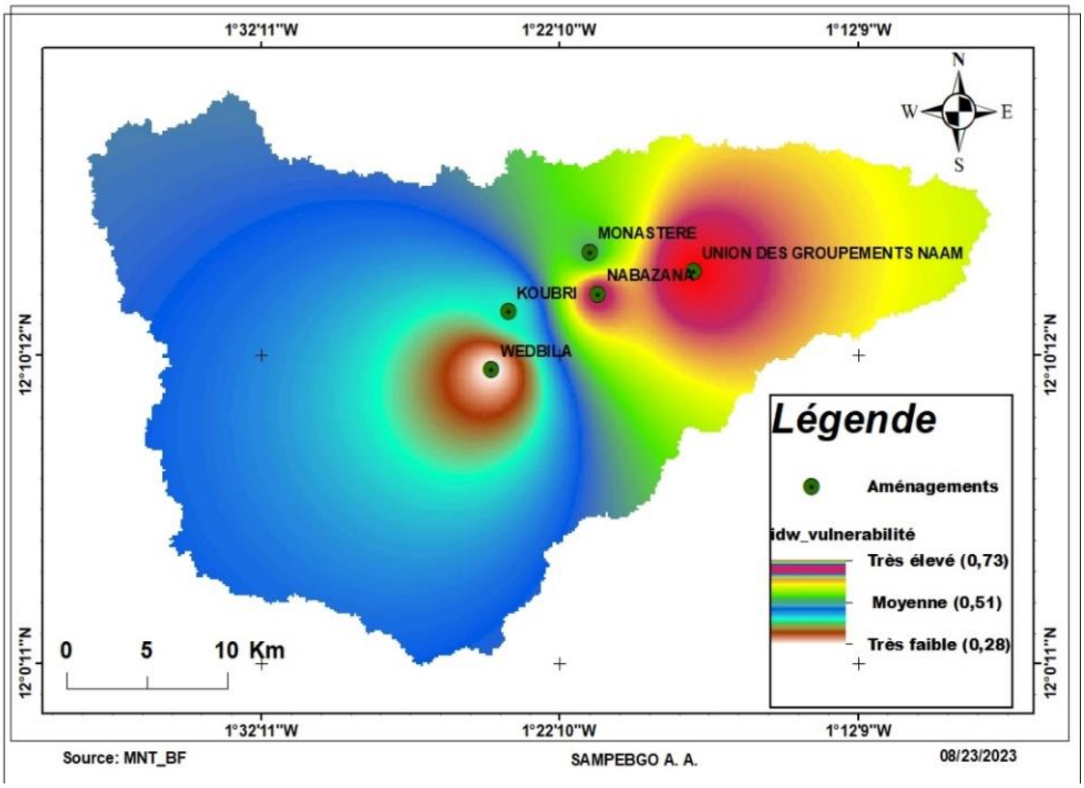
The results show that the authorities must put in place soil policies for irrigation schemes in order to reduce their levels of vulnerability to erosion and water stress.

3.3 Climate Risks

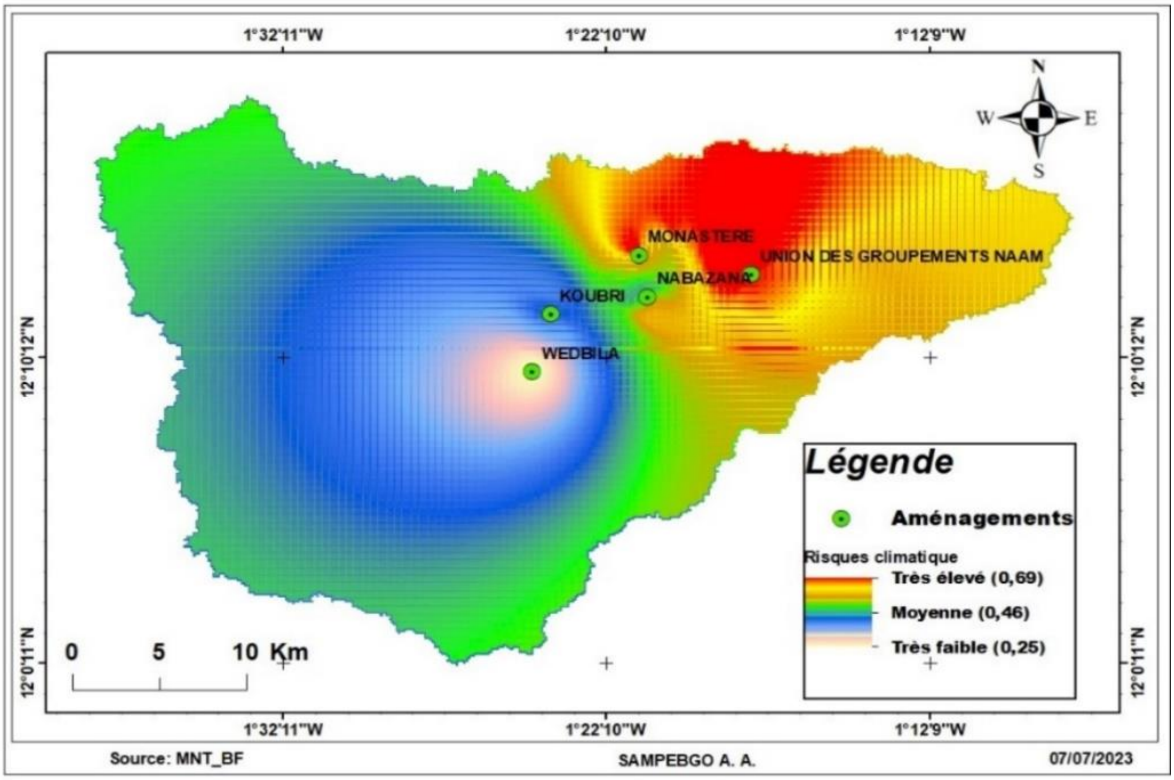
The level of risks remains very high in the irrigation schemes of Boussouma followed by those of the Monastery. Those of Nabazana remain moderately exposed to climate risks. The Koubri and Wédbila developments are respectively weakly and very weakly exposed to climate risks (Map 11). Adaptation to risks remains a priority at the Boussouma, Monastère and Nbazana perimeters.

The perception of stakeholders on practices and techniques for adaptation to climate risks gives the following results (Table 5)

- Total absence of practices and techniques for prevention or anticipation of climate risks (mechanisms for mobilizing resource actors, risky behaviors, alert systems, acquisition and dissemination of information).
- Total absence of practices and techniques for monitoring and evaluating climate risks.
- Low practice of techniques for reduction or resilience to climatic risks (mulching in the event of high heat , abandonment of irrigated areas to flooding and water stress).



Map 10. Vulnerabilities climatic



Map 11. Risks climatic

Table 6. Perception of stakeholders on practices and techniques for adaptation to climate risks

Irrigated areas	Number of respondents	Risk adaptation practices and techniques		
		Prevention or anticipation (%)	Reduction or resilience: mulching (%)	Monitoring and evaluation (%)
NABAZANA	15	0	43	0
WEDBILA	65	0	85	0
PK 25 DOWNSTREAM	25	0	76	0
MONASTERY	15	0	65	0
SOUGRI NOOMA	30	0	56	0

Source: SAMPEBGO AA 2023

4. DISCUSSION

The study of the climatic hazards of the Nariarlé watershed shows that irrigation developments are subject to the effects of climate change as a whole. These results are in line with those of AP Ouoba, (2013) whose studies on climate change and vegetation dynamics, carried out in the Burkinabè sahel as well as Le Barbé & Tapsoba , (1994) in the characterization of fluctuations interannual rainfall in the Sahel. The period 1950-2020 is marked by a very high level of vulnerabilities to temperatures (45.75°C) and precipitation (98.7mm). The temperature of each decade (1980) has been warmer than all those which preceded it since 1850. These results are in conformity with the work of Hallouz et al. [36, p. 07] ; of IPCC [33, p. 28] ; of report five of IPCC [37, p. 07] and the World Meteorological Organization [10, p. 06] . The analysis of complementary risky practices and strategies reveals that the developments are very exposed to additional risks. Piping or collection of aggregates (sand , gravel) on the dikes and nest of dams and the growth in the $CO_{2\ \text{level}}$ on the ground demonstrates the threats to adaptation strategies. The irrigation schemes of the Nariarlé watershed constitute a set of systems vulnerable to erosion and water stress [38, p. 112], [39, p. 106], [40, p. 13] . The protection of the soil by vegetation depends on the nature of the land use and the density of cover.

5. CONCLUSION

The analysis of hazards, exposures and vulnerabilities of irrigation schemes in the Nariarlé watershed reveals that irrigation schemes in the watershed are exposed to climatic risks. The watershed is experiencing strong population growth. Measures for management, acquisition and dissemination of information related to climate change remain weak overall. Risky behaviors are accentuated with incivism. External support (project/program) for risk and exposure management is limited to mulching techniques (in extreme heat) or the simple abandonment of irrigated areas to the vulnerabilities of climatic hazards (floods, water stress). In the short term, the assessment of risks linked to changes implies an improvement of the system and mechanisms for monitoring and evaluating studies of risks linked to climate change of developments, mobilization (actors-resources), availability of material means resilience and alert systems (mechanisms, tools, equipment, monitoring, etc.). In the long term, this study constitutes a decision support tool in terms of choice and priority of intervention for more effective management of climate risks and attacks on food security in Africa. [41, p. 26], [42, p. 06], [43, p. 10], [44, p. 04], [45, p. 22], [46, p. 06] .

As recommendations or perspectives, political decision-makers and practitioners in the field must strengthen the economic efficiency of developments through financing policies, mitigate the risks of climatic hazards through awareness-raising, training, and supervision of stakeholders in evaluation methods. climate risks. It is also necessary to strengthen the availability and management of water resources through better monitoring of hydraulic infrastructures and their rehabilitation by integrating groundwater pumping systems using solar panels.

DECLARATIONS

Accessibility of Climate Data : “The authors declare that the data underlying the work are accessible. These data are accessible to the national meteorological agency of Burkina Faso (ANAM-BF). Order number 2022/65”.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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