Induced Effects of Climate Variability and Anthropogenic Pressures on Land-Use Dynamics in the Awa Data Sub-Basin (1975-2025), North Dogondoutchi, Niger

Karimou Dia Hantchi[1,2], **Salissou Ibrahim Yahaya**[2], **Hallarou Mallam Mamane**[3], **Oumarou Zango**[4], **Mahamadou Sani Moussa**[5], **Rabiou Abdou**[4], **Laouali Abdou**[6], **Souleymane Zango Maïnassara**[2], **Moussa Konaté**[3]

[1]Water Sciences, Mineral Resources, Uses and Management UMR, Dan Dicko Dankolodo University, Maradi, Niger; [2]Georesources and Environmental Geosciences Laboratory, André Salifou University, Zinder, Niger; [3]Groundwater and Geosciences Laboratory, Abdou Moumouni University, Niamey, Niger; [4]Laboratory of Ecology and Management of Sahel-Saharan Biodiversity, André Salifou University, Zinder, Niger; [5]Department of Natural Resources and Environment, Faculty of Agronomic Sciences, Djibo Hamani University, Tahoua, Niger; [6]Department of Biodiversity and Plant Productions, Faculty of Agricultural Sciences, University of Diffa, Diffa, Niger

Correspondence to: Karimou Dia Hantchi, diah.uddkm@gmail.com

Keywords: Climate Variability, Hydro-Erosion, Impacts, Opportunities, Awa Data, Niger
Received: January 2, 2026 **Accepted:** March 23, 2026 **Published:** March 26, 2026

ABSTRACT

In Niger, climate and environmental changes pose a threat to community development, particularly to achieving their poverty reduction and sustainable development goals. This study aims to analyze the impacts of climate variability and anthropogenic pressures on landscapes in the Awa Data sub-basin (North Dogondoutchi, Niger), in order to identify the opportunities and challenges faced by local communities in their adaptation strategies. To achieve this objective, primary (surveys) and secondary (climatological and satellite imagery) data were collected and compared with observations made during field visits. Analysis of secondary (climate) data and perceptions of residents aged 45 and over (N = 80) regarding the impacts of climate variability and human actions indicates an upward trend in the intensity of precipitation, temperatures and wind strength, as well as a deterioration of vegetation. The spatiotemporal study of land cover units in the sub-basin reveals an increase of 5% for cultivated areas and 2% for water bodies, against a decline in local vegetation cover estimated at 16% over the period 1975-2025. The respondents (80%) attribute these trends to climate variability and the conquest of new arable areas and habitats, which are linked to rampant population growth and its additional impact on already limited natural resources. The impacts of this environmental deterioration are the phenomena of water erosion, in terms of an increase in the competence

of runoff waters, the undermining of banks by vertical and horizontal gullying, the silting up of lowlands, fragmentation of points by lateral flows at the origin of sand cones and flooding following the rapid emptying of almost filled ponds. The challenge is undoubtedly the increasing loss of water depth, essential for irrigated crops in the sub-basin. Biomechanical land management structures (half-moons, terraces) and water management structures (spreading sills) have a considerable impact on the development of the community's productive base potential, especially since they constitute the only buffer against the most frequent climatic hazards in the sub-basin.

1. INTRODUCTION

The Republic of Niger, a landlocked country in the Sahel region of West Africa, is particularly vulnerable to the effects of climate change [1]. The spatiotemporal variability of rainfall, rising temperatures and the increased frequency of extreme climatic events directly impact natural resources and agricultural systems [2]. As a result, food security and the livelihoods of populations are increasingly threatened by climate risks and land degradation [3-5]. This land degradation, attributed to a range of impacts related to several constraints on agricultural production in rural areas, is responsible for the decline in soil fertility [6]. Through unsustainable practices such as uncontrolled deforestation, a rapidly growing population is also putting increasing pressure on arable land [7, 8].

In the Northeastern sector of Western Niger, between the Bosso Dallol (Tillabéry region) and the Maouri Dallol (Dosso region), many authors have reported clarifications on climatic deterioration and land occupation dynamics. Thus, [9] reported that "the consensus information collected from the local populations of the rural commune of Abala (Filingué, Tillabéry region) clearly shows that agricultural producers directly perceive climate change through the frequency of violent winds, the irregularity, the poor distribution and the decrease in rainfall as well as the rise in temperatures". According to [10], from 1973 to 2018, "the natural vegetation of the rural commune of Dogonkirya (Dosso region) experienced a significant decline (85.23%) in its area in favor of cultivated areas, bare soils and ponds which respectively increased from 30.10% to 57.36%, then from 8.10% to 29.51% and from 0.7% to 4.1% of the area of the commune". As for the central areas of the Dogondoutchi department (Dosso region), [11] reports that the large bays of the lowlands around the Birnin Lokoyo sub-basin are silted up or eroded. The north of Dogondoutchi, and more specifically the Koléfo watershed, is characterized by bodies of water that are completely silted upstream [12]. This author notes that the silted-up pond of Koubi has moved towards the bed of the Dallol Maouri in the West as far as the village of Koléfo in the South. On the other hand, some sectors of this large fossil valley are transformed into fields on sandy deposits of aeolian origin and/or new wooded areas of *Faidherbia albida* species [13]. Therefore, the influence of climatic disturbances (insufficient, torrential, irregular and poorly distributed rainfall; sudden floods and inundations; frequent winds and severe drought; intense heat, ...) and certain human practices represents major challenges, but also opportunities for sustainable development for communities able to adapt to them [14-17].

This study, focused on the "Impacts of climate variability and anthropogenic pressures on land use dynamics between 1975 and 2025", concentrates on the specific case of the Awa Data sub-basin, located north of the Dogondoutchi department (Dosso region) in Niger. The multi-hazard approach combines the analysis of a series of satellite images, local knowledge, and field observations. The main objective is to analyze land-use changes between 1975 and 2025, in relation to climate change and anthropogenic pressures, including rainfall disturbances, land use and planning. The specific objectives assigned to this work are to: (i) understand the perceptions of human entities within the sub-watershed regarding their understanding of climate and environmental changes, (ii) identify the dominant factors driving landscape transformation in Awa Data, and (iii) assess the opportunities and challenges for local communities.

2. MATERIAL AND METHODS

2.1. Study Area

The Awa Data pond sub-basin is part of the Northeast branches of the North Dallol Maouri [18], a synclinal depression linked to the Iullemmeden sedimentary basin [19] (**Figure 1**). The study was conducted in the lowest part (main outlet of the sub-watershed) centered on the Awa Data pond (**Figure 1(B)**) and between longitudes 3˚52'16" and 4˚05'00" East and latitudes 14˚01'40" and 14˚07'55" North (**Figure 1(A)**). The semi-arid climate is characterized by two main seasons: a dry season from October to May and a rainy season from June to September. The dry season includes a cool, dry period and a hot, dry period. It is characterized by the circulation of hot, dry winds (the Harmattan). The rainy season is characterized by moisture-laden winds that generate rainfall in the Sahelian latitudes (the monsoon) [20]. Average annual rainfall, which is irregular, varies between 300 mm in the north and 450 mm in the south [21].

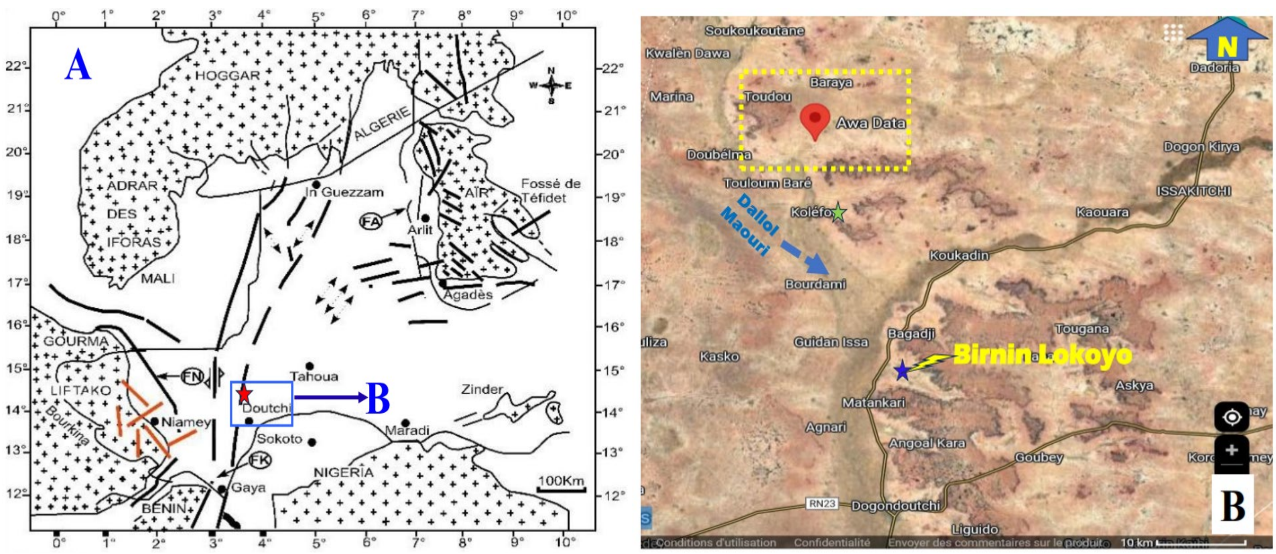

Figure 1. Location of the study area. (A) Awa Data (red star) in Niger and the Iullemmeden syncline shaped basin (between the 3˚E and 4˚E meridians), showing FA (Arlit Fault), FN (Niger Normal Fault) and FK (Kandi Fault) [19]. (B) The Awa Data sub-basin (the yellow rectangle) in the Dallol Maouri valley (50 km from Doutchi also known as Dogondoutchi) (Source: Google Earth 2025).

The common relief is characterized by three major sets, namely: (i) Continental Terminal 3 (CT3) outcrops are represented to the South by a chain of regular arc-shaped hills, a plateau in the Northwest and a string of isolated hills in the North; (ii) Dune plateaus on the slopes and (iii) lowlands and sand deposits located in the minor bed of the Dallol Maouri [12, 22]. In this topography, the structural configuration would be controlled mainly by N-S to NE-SW fractures, which are extensions of the major faults affecting the Hoggar basement (**Figure 1**), then E-W to NW-SE, attributed to the opening of the Atlantic Ocean [19]. It can be observed that most of these lineaments coincide with the hydrographic network (**Figure 2** and **Figure 3**). These four directions are consistent with the flow directions of the main kori (Wadi) (E-W and NE-SW) and those of the secondary basins (N-S and NW-SE [23, 24]) (**Figure 2**). The surface hydrographic system in the study area consists of: (i) wetlands in the fossil valley of the Dallol Maouri and (ii) a series of ponds along NE-SW fractures, the main ones being the Awa Data and Bouzouzou ponds (**Figure 2** and **Figure 3**). The deepwater resource includes the alluvial aquifer of the lowlands (Dallol Maouri and Awa Data sub-basin) and Continental Terminal 3 (CT3), in addition to the aquifer supplying the middle Continental Terminal (CT2) [25]. For many authors [19, 22, 23], the CT3 is the "formation of oolitic clayey sandstones with a ferruginous crust of the Middle Niger", while CT2 is the "clayey-sandy lignite formation".

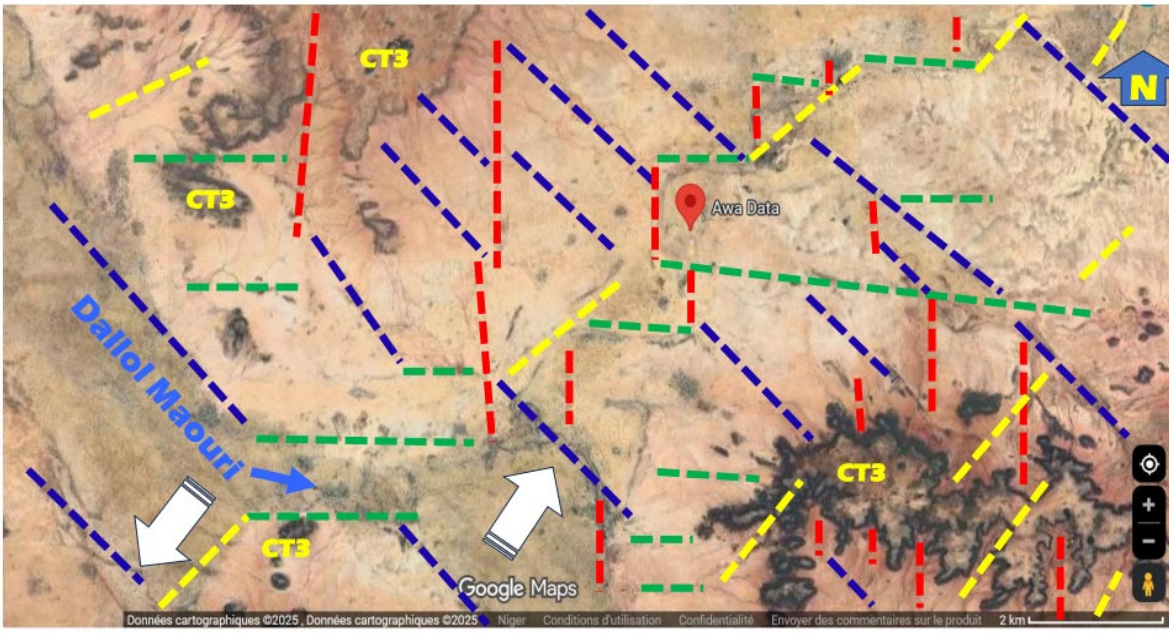

Figure 2. Main fracture networks (NW-SE in indigo; E-W in green; N-S in red and the main Kori mimicking NNE-SSW and NE-SW in yellow) in the Awa Data Sub-basin (Google Earth 2025). The red dot marks the pond of the same name in the Sub-basin. The CT3 are the Continental Terminal outcrops. The white arrows indicate the average direction of the strike slip faults displacement [19].

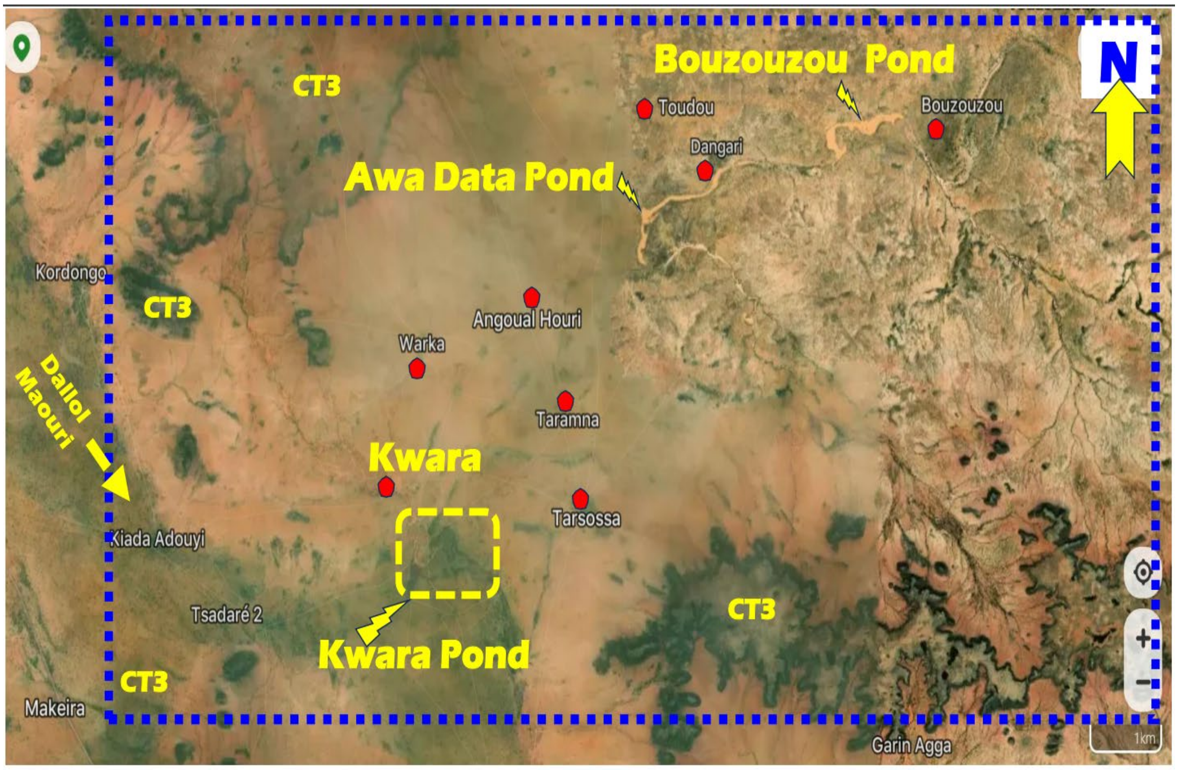

Figure 3. The surface hydrographic system in the study area. In this photo, CT3 represents the various kind of outcrops of the Continental Terminal formation (Source: Google Earth 2025).

The population in the sub-basin was estimated at approximately 3000 inhabitants in 2016 [26]. As throughout Niger, agriculture is the primary economic activity in and around the villages [27]. Livestock farming is the second most important economic activity for the population in the study area. Trade, the third most common economic activity, is practiced by both men and women [27, 28].

2.2. Methodological Approach

The methodological approach adopted for this study includes three (3) stages. The first stage was devoted to a literature review of scientific articles, dissertations, and theses related to this study. The second stage consisted of mapping and analyzing land dynamics using satellite data. The third stage was based on data collection primarily in the field, initially using a survey questionnaire administered to the sub-basin population, followed by a series of exploratory visits and observations of the field conditions.

2.2.1. Documentary Research Data

The analysis of the literature allows us to use current knowledge on the dynamics of surface water resources in Niger. This also enabled us to compile secondary data, including annual averages and the number of rainy days per year at the Soukoukoutane station between 1992 and 2022 [12].

2.2.2. Mapping Data

The mapping data used are *Google Earth* imagery and *LANDSAT* satellite images from 1975, 2000, 2014, and 2025, downloaded free of charge from https://earthexplorer.usgs.gov. The acquisition periods considered for these images, which have a ground resolution of 30 m, are recorded in **Table 1**. It would have been desirable to have sequences from the years 1975, 1985, 1996 and 2016 to cover the last 41 years, but the limited availability of satellite images in the study area imposed the only choice of those from the years 1975, 2000, 2014 and 2025. These four scenarios, with fewer residual clouds and sandstorms, are based on the months of October and November (**Table 1**). Indeed, in the Sahel, at this time of year, the herbaceous vegetation resulting from the wet season (June to September) has almost disappeared, to such an extent that the values of the Normalized Difference Vegetation Index (NDVI) correspond only to permanent woody vegetation [4, 12].

Table 1. Characteristics of Landsat satellite images.

Assignment	Acquisition date	Resolution	Number of bands
Landsat 2	02/11/1975	60 m	04
Landsat 7	03/10/2000	30 m (multispectral)	08
Landsat 8	03/11/2014	30 m (multispectral)	11
Landsat 9	21/10/2025	30 m (multispectral)	11

Source: https://earthexplorer.usgs.gov/.

The satellite images first underwent preprocessing, followed by supervised extraction and classification, before any map production. Image preprocessing is essential because some images (particularly older ones) have defects that must be corrected before use [29]. This involves performing geometric (or calibration) and radiometric corrections to make the data usable. We resampled the Landsat 2 images to a resolution of 30 m. The spectral bands required for classification (bands 1 to 4 for Landsat 2, bands 1 to 5 and 7 for Landsat 7, and bands 1 to 7 for Landsat 8 and 9) were extracted and converted to top-of-the-atmosphere (TOA) reflectance. Finally, the study area was extracted from a vector file (Shapefile) representing its boundaries. To do this, spatial masking was performed using the Clipping tool, limiting the analysis to the relevant area (here, the inset corresponding to the Awa data sub-basin).

Supervised classification was then carried out using the maximum likelihood method (MLM). Training samples (or training sites) were thus visually collected for each identified land cover class (water bodies, bare soil, cultivated areas, rock outcrops, and vegetation) [30]. Indeed, objects in the image with a similar spectral signature are considered to belong to the same class and are therefore grouped into five classes. When a linear structure was of anthropogenic origin (rural tracks, field fences, boundaries of cultivated areas, etc.), it was removed. This qualitative assessment was carried out using *Google Earth* images, the geological map, and the topographic map extracted from the digital terrain model (DTM).

The study aimed to assess variations in area (in hectares) covered by surface water, vegetation, crops, bare soil, and other features, using statistical calculations. The classification was finalized using the standard ArcGIS Image Classification tool. The final land cover map was generated with ArcGIS 10.8®, using a layout that included standard map elements: legend, orientation, scale, coordinate system, year, and a graph of land cover units with their percentage. The resulting series of maps were also validated following a quantitative evaluation focused on four parameters: overall accuracy, Cohen's Kappa coefficient, confusion matrix, and separability matrix [4, 12].

2.2.3. Data from the Survey, Interviews, and Observation of the Reality on the Ground

In order to capture the memory map of landscape changes that have occurred in the study area, the surveys involved people aged at least 45 years. The summary used as the basis for constructing a sample of 80 people was obtained through group (meeting) and individual interviews in five (5) villages. These were the villages of Dangari (n = 35), Tarsossa (n = 25), Awa Data (n = 10), Angoual Houri (n = 5) and Bouzouzou (n = 5) (**Figure 3**). The choice of these villages is based not only on the quantity and diversity of agricultural actors they contain, but also on their proximity to land reclamation areas (as in the case of Tarsossa) or to the developed lowlands in the main kori of the sub-watershed (**Figure 3**). Also, to gather more information, clarifications or specific guidance relevant to cross-referencing the data, additional interviews were conducted with some village chiefs from the sample.

The study area was therefore classified as a major insecurity zone and with the use of motorcycles prohibited, so we used our own feet for all movement on the ground. A smartphone was used to communicate with village respondents, not only to capture field images but also to enter their responses directly into Microsoft Word® documents. A laptop was used for data entry and processing. Microsoft Excel® (version 2016) was used for data processing and visualization.

3. RESULTS

3.1. Characteristics of Rainfall Variability between 1997 and 2022

Total daily rainfall at the Soukoukoutane synoptic station (1997-2022; **Figure 4(A)**) shows significant annual variation, with a minimum of 8.42 mm/day in 2002 and a maximum of 23.09 mm/day in 2020, representing a standard deviation of 4.25 mm/day. Despite this strong interannual fluctuation, an increase in rainfall of approximately 12 to 19 mm/day/year was observed over the period 1997-2022, indicating a progressive intensification of total daily rainfall over the last 25 years (red linear trend; **Figure 4(A)**). Concurrently, after an increase that might have suggested an improvement in climatic conditions between 1997 and 2003, the number of rainy days per year (**Figure 4(B)**) decreased from 41 days/year in 2003 to 23 days/year in 2022.

3.2. States and Dynamics of Land Occupation in the Awa Data Sub-Basin (1975-2025)

Figure 5 shows the land cover map of the Awa Data sub-basin in 1975 (A) and 2000 (B). **Table 2** shows the distribution of the land cover classes retained in 1975 and 2000.

In these two illustrations, the explanatory value is the regression of outcrops and vegetation which respectively decreased from 10.92% in 1975 to 7.89% in 2000 and from 19.38% in 1975 to 6.41% in 2000 (**Table 2**). However, an increase (**Table 2**) in water bodies (0.06% to 0.75%), cultivated areas (54.29% to

59.85%), and bare soil (15.35% to 25.10%) can be observed throughout the sub-basin (Figure 5). As a result, the vegetation that was once found on the slopes of the sub-basin (Figure 5(A)) is now concentrated mainly in a few low-lying areas and the minor beds of the koris (Figure 5(B)).

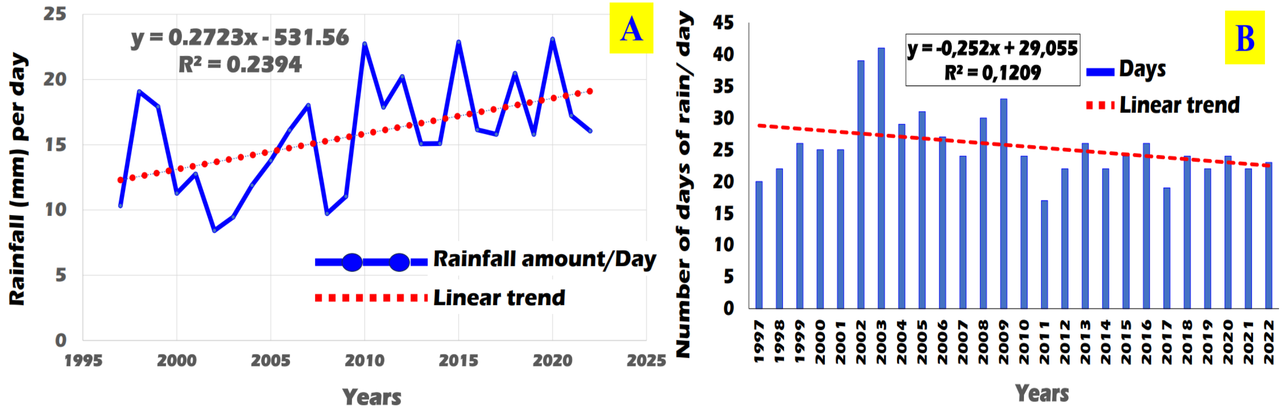

Figure 4. Time series of cumulative rainfall recorded at the Soukoukoutane station from 1997 to 2022 [12]. (A) Annual rainfall per day. (B) Trend in the number of rainy days recorded per year.

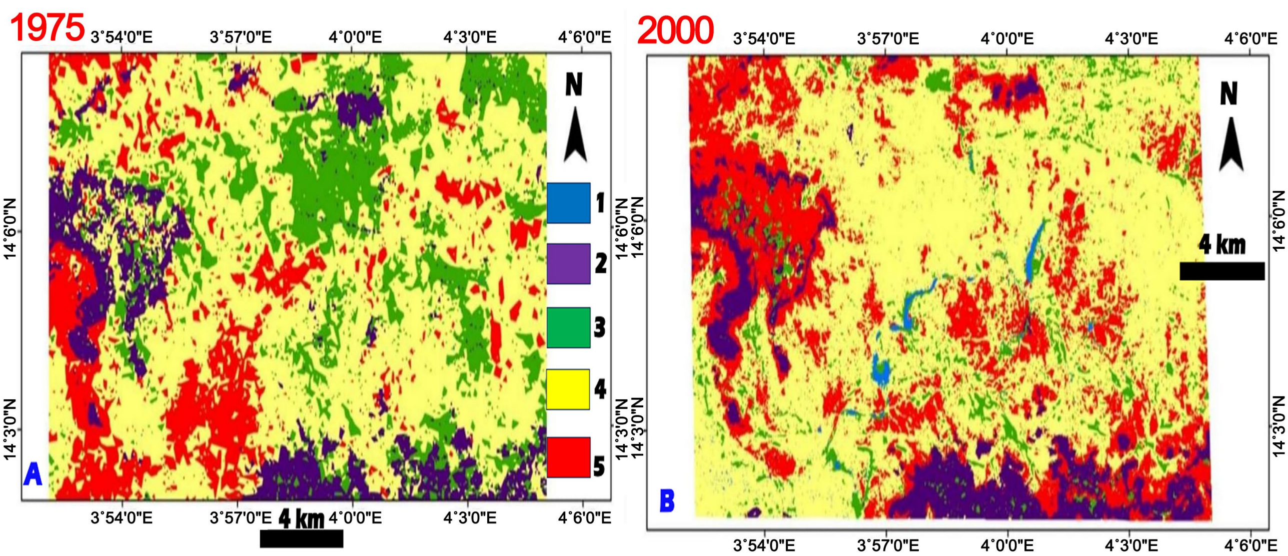

Figure 5. Map of land use patterns in the Awa Data sub-basin in 1975 (A) and 2000 (B) (Zango 2025). The symbols in legends 1, 2, 3, 4 and 5 correspond respectively to bodies of water, rock outcrops, vegetation, cultivated areas and bare soils.

Table 2. Distribution of land use in the Awa Data sub-basin in 1975 and 2000.

Year	Occupancy Units and Percentage				
	Bodies of water	Rock outcrops	Vegetation	Cultivation areas	Bare soils
1975	0.06%	10.92%	19.38%	54.29%	15.35%
2000	0.75%	7.89%	6.41%	59.85%	25.10%

Figure 6 represents the land cover map of the Awa Data sub-basin in 2014 (Figure 6(A)) and 2025

(Figure 6(B)), and Table 3 gives the continuation of the distribution of their occupation classes during the same period.

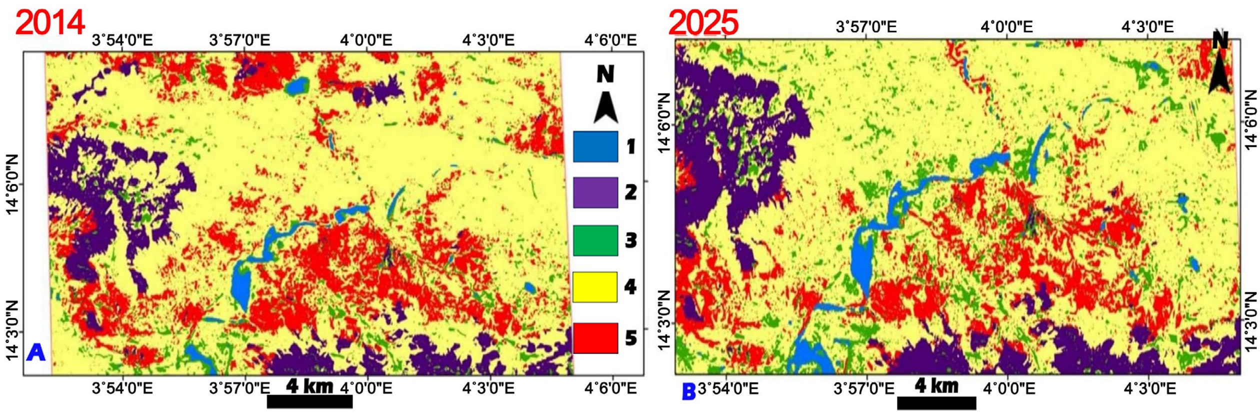

Figure 6. **Map of land use patterns in the Awa Data sub-basin in 2014 (A) and 2025 (B) (Zango 2025). The symbols in legends 1, 2, 3, 4 and 5 correspond respectively to water bodies, rock outcrops, vegetation, cultivated areas and bare soils.**

Table 3. **Distribution of land use in the Awa Data sub-basin in 2014 and 2025.**

Year	Occupancy Units and Percentage				
	Water bodies	Rock outcrops	Vegetation	Cultivation areas	Bare soils
2014	1.25%	11.92%	5.37%	62.73%	18.73%
2025	2.64%	12.00%	9.00%	63.00%	13.36%

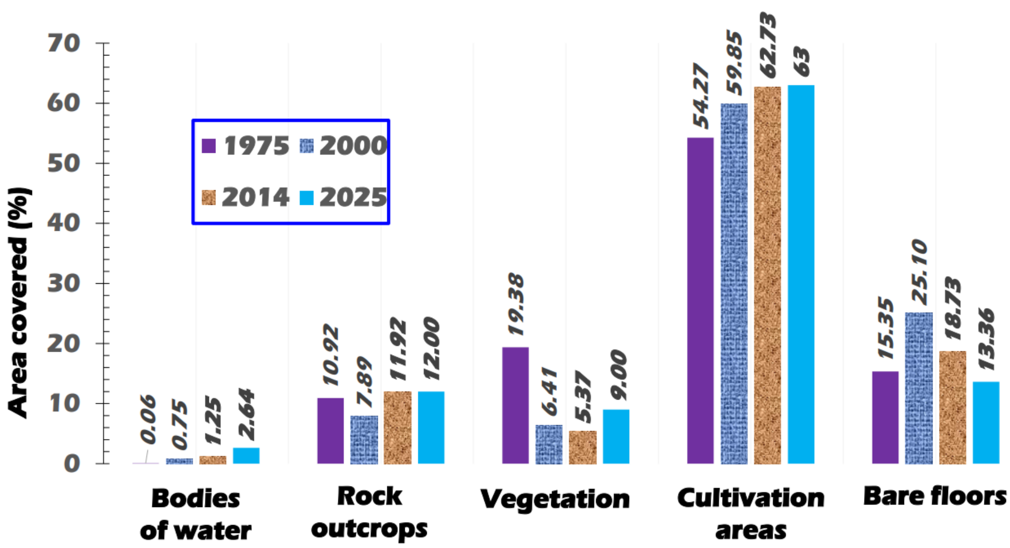

Figure 7. **Diachronic evolution of land cover units in the Awa Data sub-basin from 1975 to 2025.**

The areas occupied by bodies of water and cultivated areas continued to increase (Table 2 and Table 3). Thus, bodies of water increased from 0.75% in 2000 to 1.25% in 2014 and is projected to reach 2.64% in 2025, while cultivated areas, which were 59.85% in 2000, are expected to reach 62.73% in 2014 and 63% in

2025. At the same time, the proportion of bare soils, which increased from 15.35% in 1975 to 25.10% in 2000, stabilized at 13.36% in 2025, slightly below the 15.35% of 1975 (**Table 2**). However, vegetation and rock outcrops, which had been losing ground, are now increasing in area. In fact, vegetation cover decreased from 6.41% (in 2000) to 5.37% (in 2014) and is projected to reach 9% in 2025, while also becoming denser in both the low-lying areas around the water and on the previously degraded lateritic plateaus (**Figure 6(B)**). Furthermore, rock outcrops, which covered only 7.89% in 2000, are expected to stabilize at around 12% between 2014 and 2025.

In general, both in the valley areas and on the plateaus, it is accepted that the Awa Data sub-basin has experienced increasingly intermittent changes over the last fifty years (**Figure 7**). These results show that while extensive farming is clearly on the rise, this activity alone cannot explain the trends observed in other land cover units, particularly those related to the dynamics of rock outcrops and vegetation since the early 2000s.

3.3. Common Perceptions of Climate Variability and Its Impacts on the Environment

Local tradition holds that agricultural activities, and therefore memories of wintering, are still purely masculine. The survey sample (N = 80), consisted solely of men, ranging in age from 45 to 50 years (55%), 51 to 65 years (17%), and 66 to 80 years (28%). In the study area, 100% of respondents reported observing significant changes in rainfall patterns. According to the respondents, rainy seasons are becoming increasingly shorter (65%) and/or the onset of rains (which are even less regular) is delayed or occurs very early (35%). All respondents reported a rise in temperatures, with a very long hot season nowadays, lasting approximately five to six months (February to July). One survey participant testified: "Thirty to forty years ago, one could walk barefoot for long distances in the bush without losing consciousness, which is practically impossible today".

Those interviewed also reported an intensification of strong winds during the dry and cool seasons (70%) and at the beginning of the rainy season. Respondents (30%) emphasized that these winds cause damage to crops and infrastructure. During discussions, the elders stated that the frequent and strong winds in all seasons contribute to the depletion of vegetation due to uncontrolled deforestation. For 80% of respondents, this vegetation (very dense 50 - 60 years ago) was essential for maintaining the ecological balance of the study area. Unanimously, respondents support the view that vegetation cover plays crucial roles in climate regulation, preventing erosion and soil drying, protecting water resources, and conserving biodiversity.

Figure 8. Image (Zango 2025) showing the state of the soil and vegetation cover in the Awa Data sub-basin. It can be seen that the ravines (e.g. in the foreground) form unique climax communities for the increasingly stunted vegetation.

Beyond climate variability, communities therefore assert that there is an increase in human occupation, because the increase in human needs (firewood and other uses of life) increases the pressure on the already limited plant space (Figure 8). It is worth nothing that men are still the only ones who take care of clearing and felling firewood. The women are content to collect only the dead branches. Among the causes of environmental degradation attributed to climate change, water erosion stands out as the most prominent phenomenon. For all respondents, during and after the rainy season, water erosion (Figure 8) has direct impacts on agricultural yields and the quality of life of the population.

Field observations confirm that in the Awa Data sub-watershed, water erosion manifests upstream as (i) sheet erosion on agricultural slopes, leading to the loss of topsoil, and (ii) incised drainage channels (koris), resulting in the formation of steep and highly unstable banks, as well as the development of deep gullies (Figure 9). Furthermore, human traffic, in the form of tracks traversing gorges between the CT3 plateaus or koris beds, contributes to the undermining of embankments and the weakening of bank soils through hydro-erosive gullying (Figure 10).

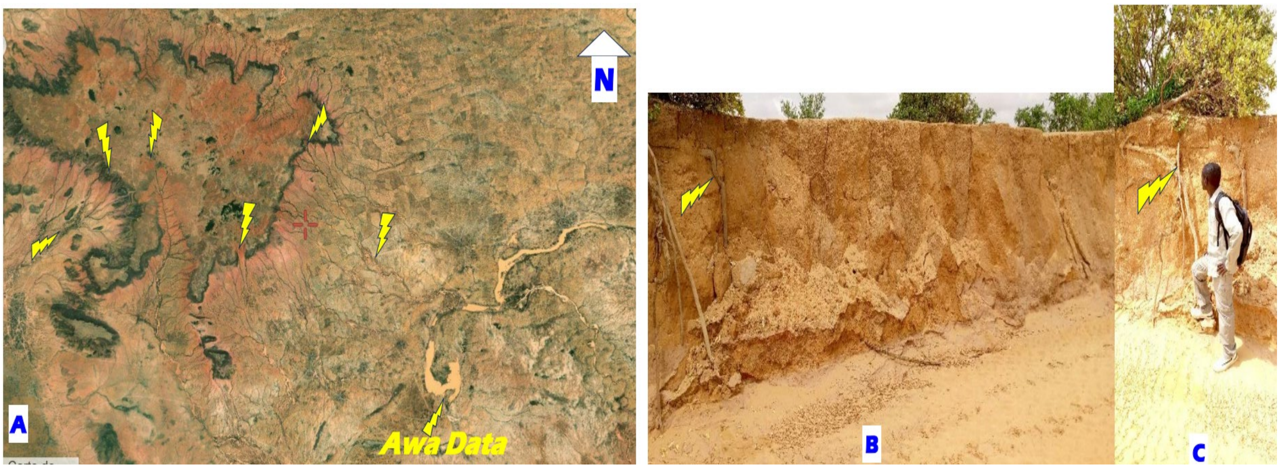

Figure 9. Visible signs of water erosion: (A) Concentrated runoff along embankments and slopes (Source: Google Earth 2025); (B) Uprooting of a tree; (C) Deep gully in the sub-basin (Zango 2025).

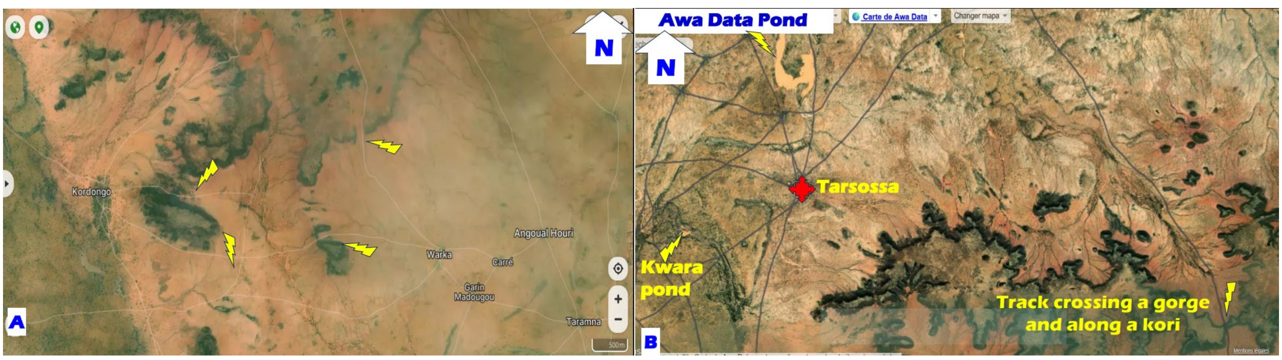

Figure 10. Roads facilitating hydro-erosion. (A) Capture via embankments of headward erosion in the Kwara sub-basin. (B) Track in a gorge between the Koléfo (in South) and Awa Data (in North) basins (Source: Google Earth 2025).

On the other hand, the consequences of hydro-erosion in downstream areas include the silting up (Figure 11) of low-lying areas and large bodies of water (Figure 11(A), Figure 11(B)), which reduces their capacity to store runoff from the banks. The silting up of the Awa Data valley also means sand avalanches in alluvial fans of secondary koris (NW and SE; Figure 11(C)) which cause fragmentation and beading of water points along the main kori.

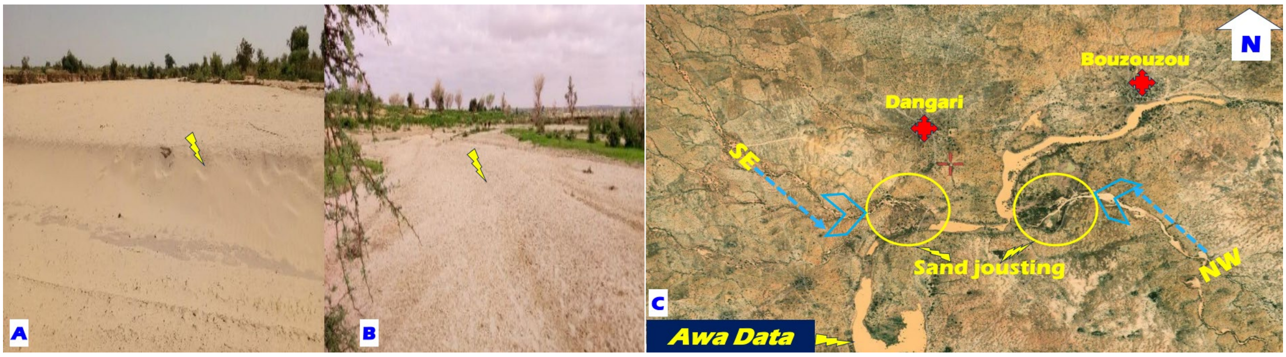

Figure 11. **Siltation of a kori bed (A), a wetland (B) (Zango 2025) and semi-permanent water points (C) (Google Earth 2025). The yellow circles correspond to sandy alluvial fans resulting from lateral flows from the banks (NW and SE) which fragment the main flow into small pools.**

3.4. Community Adaptation Strategies in the Face of Climate and Environmental Changes

Faced with the increasing impacts of climate and environmental changes (drought, rainfall variability, soil degradation), those interviewed state that local communities have developed or adopted both traditional and modern adaptation techniques. The most widely used technique is soil amendment in fields, followed by assisted natural regeneration (ANR; Figure 12(A)) and the practice of off-season crops or market gardening (Figure 12(B)).

Figure 12. **Illustrations of assisted natural regeneration (ANR) practices (A) and irrigated crops (B) in the Awa data sub-basin (Zango 2025).**

Irrigated crops (Figure 13) mainly include Soukoukoutane white onion (Figure 13(A)), squash, beans and cassava, as well as fruit crops (citrus and mangoes; Figure 13(B), Figure 13(C)).

The survey shows that the least adopted techniques among the populations are the use of improved varieties and the planting of trees in fields or on plateaus and glacis. However, within the framework of comprehensive and strategic interventions, there are works derived from modern techniques of sustainable water and land management (Figure 14 and Figure 15), including a spreading threshold at the permanent pond of Awa Data (Figure 14(A)) and crescent-shaped fields (on the cuirassed plateaus and on the banks; Figure 14(B)) and banks on the plateaus of CT3 (Figure 15).

Figure 13. **Main irrigated crops in the sub-basin: (A) white onion from Soukoukoutane, (B) and (C) horticulture on the edge of the Bouzouzou pond (Zango 2025).**

Figure 14. **Sustainable water and land management techniques in the sub-basin: (A) Awa Data spreading weir and (B) half-moon fields on the banks (Zango 2025).**

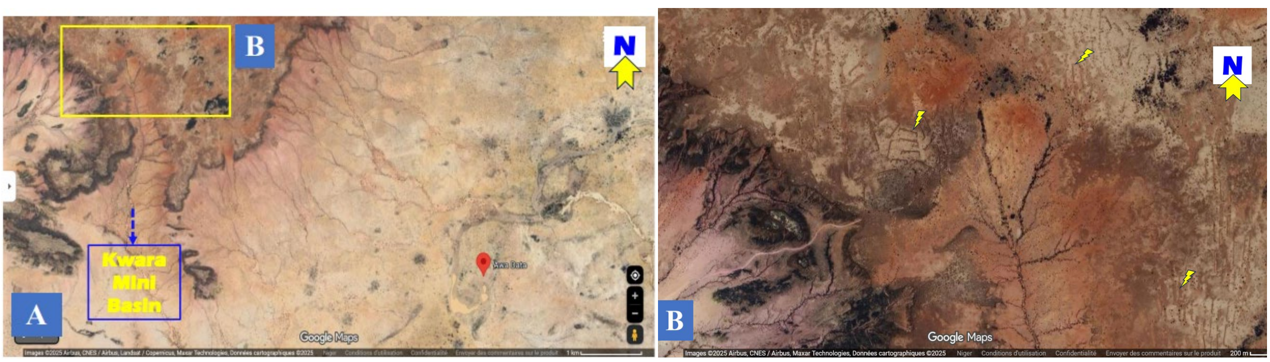

Figure 15. **Sustainable land management techniques in the Awa Data sub-basin. (A) View of the Northwest plateaus and the Kwara min basin. (B) Inset showing the benches in the upstream areas of the Kwara mini-basin (Source: Google Earth 2025).**

4. DISCUSSION

The question of the environmental consequences linked to climate variability and human pressures is currently at the center of debates. Regarding the impact of climate change, one of the greatest concerns remains the framing of the deterioration of living conditions and resources of populations, particularly through the intensification and extensification of productions on already very limited land [8, 10-12, 23, 31-34]. It is within this fundamental reflection that this study examines the dynamics of land occupation, the socio-environmental challenges and opportunities in the outlet sub-watershed of a small tributary of the fossil valley of the North Dallol Maouri.

4.1. Landscape Transformation Dynamics through the Lens of Climate Change in the Awa Sub-Basin

A diachronic analysis of LANDSAT satellite images of the Awa Data sub-basin revealed that natural vegetation, consisting mainly of tiger bushes, declined by 10.39% of its area between 1975 and 2025 (**Figure 7**). Interviewees indicated that this trend is linked to the exploitation of vegetation cover, very often exacerbated by overgrazing and aggravated by the lack of plant resource conservation practices. According to [12], the disappearance of vegetation cover, in addition to reducing local biodiversity, promotes strong rainwater runoff and increases the risk of water erosion, while exposing soils to climatic hazards. Thus, in areas of higher flow, erosion due to bank retreat is linked not only to landslides, but also to soil transport, which weakened rock outcrops between 1975 and 2000. Given that the terrain is characterized by friable lithology and sparse vegetation (**Figure 8**), the weakening of the rock outcrops is explained by their tendency to subside. Indeed, the occupation rate of the outcrops decreased from 10.92% in 1975 to 7.89% in 2000. The accumulation of sand (**Figure 11**), frequently mentioned by the residents interviewed, corresponds first to the borrowing resulting from the degradation of the summit formations of CT3, which disappear towards the north (**Figure 9** and **Figure 10**), and then to the sedimentary inputs accentuated by the localized or continuous erosion of the sandy banks of the ravines [12]. This ablation is particularly remarkable, as the linear erosion is due to wide and deep vertical cuts along the koris descending the plateaus and carries away entire plots of agricultural land [12, 35].

From 2000 to 2025, rock outcrops become more important than during the previous period from 1975 to 2000. Indeed, this progression of outcrops (approximately 8% in 2000 to 12% in 2025; **Figure 9**) could be explained by the hydro-erosion of slopes and banks which progressively exposes the remaining basal formations of CT3 (**Figure 9** and **Figure 10**). Furthermore, Google Earth images and field visits revealed that the degradation of the CT3 formations (**Figure 9** and **Figure 10**), resulting in permanent hydro-erosion on the banks, is primarily linked to the proliferation of paths in the gorges and on the plateau glacis. The action of torrents flowing down the banks of the sub-basin remains crucial for the progression of erosion in the gorges, as it maintains a near-permanent siltation of the lower areas of the sub-basin [36]. From this perspective, listening to the stories of the elders and observing the terrain, one can see that the former large pond of Kwara is now nothing more than a wooded area, heavily invaded by sand deltas (**Figure 10(B)**). Similarly, Angoual Houri ("village of dust and dirt") aptly derives its name from the sandy deposits originating in the Northwest (**Figure 10(A)**). Indeed, the intense but brief rainfall events (**Figure 4**), frequent between May and September, generate concentrated runoff, particularly along the koris (dry riverbeds) and thalwegs (small valleys), promoting linear erosion and bank incision. These results corroborate those of [12, 23] which confirm that with an intensification of rainfall since the 1990s and a decrease in the number of rainy days during the 2000s, the capacity of rainwater to infiltrate and further destroy rock outcrops is undeniable.

The question of the dynamics of bare soils (or degraded lands here dirtying) constitutes one of the concerns both in the scientific community [1] and in the world of municipal administrators and producers in the study area (**Figure 14**, **Figure 15**). Indeed, it is worth noting that bare soils have seen a very significant increase over the periods from 1975 to 2000, a sign of accelerated land degradation, probably linked to unsustainable use of agricultural land, combined with extreme climatic events (droughts, heavy rainfall). These observations are similar to those of [10] in the commune of Dogonkirya (**Figure 1(B)**) where they showed that "the increase in bare soils and the decrease in vegetation can certainly be explained by the drastic variability of rainfall in the Sahel, but that this regression is above all consubstantial with the spatial impact of numerous human actions". This is also confirmed by [31, 37, 38] who consider that deforestation and the conversion to cultivation (here increasing from 54.27% in 1975 to 63% in 2025; **Figure 7**) of natural environments linked to population growth are the main factors in the increase in bare soil areas. The same trend was observed further west in Niger, where [36] justified the total disappearance of the tiger bush in favor of bare soils on the plateaus around Niamey (the capital city of Niger) due to the consumption of domestic wood in urban areas. In Fakara (Tillabéry region), located 60 km East of Niamey, [39] showed that 80% of the land was cleared and/or deforested between 1950 and 1992 for the expansion of crops and the need for firewood (59% of the vegetation on the plateaus was deforested and 87% of the sandy slopes were cleared). Such processes of fallow land degradation resulting from the multiple pressures (e.g. grazing, logging, re-cultivation) exerted on these areas in western Niger were reported by [40]. In Diffa, further east, the same trend is observed and explained by the expansion of cultivated and crusted areas [41].

However, when **Figure 7** reveals that from 2014 onwards rock outcrops continue to grow at the height of very aggressive erosion, the fact remains that the canopy of the sub-basin is found in the thalwegs or minor beds, or even on the old plateaus and around the ponds (**Figure 5**; **Figure 6**). It is therefore clear that other indicators, besides negative human impacts, must be taken into account. This includes biomechanical achievements in the Sustainable Land Management (SLM) component, in particular the treatment of degraded land (half-moons and benches; **Figure 14(B)**; **Figure 15(B)**) and assisted natural regeneration (ANR; **Figure 12(A)**) [1]. Furthermore, in the context of the notable return of vegetation, it is worth highlighting the rapid adoption of survival strategies by many local producers. Indeed, in order to reduce the adverse effects of the new climate situation, increasingly large areas of fruit and vegetable production have been developed in most of the lowlands of Awa Data (**Figure 13(B)**, (**Figure 13(C)**). The work of [42] has demonstrated that market gardening activities on the irrigated perimeter of Djiratawa are at the basis of a landscape beauty in South Maradi in Niger.

The bodies of water, which serve as outlets for runoff collected in the study area, have indeed seen a crucial increase in their surface area, going from some 0.06% in 1975 to 2.64% in 2025 (**Figure 7**). In the Niamey square degree [43], the term which has become established to justify the processes of increasing the surface area of water bodies is the reduction of vegetation cover, because it is favorable to the encrustation of soils in the banks and to the acceleration of runoff towards temporary or permanent water reservoirs such as ponds. Similarly, [12] in the complex Koléfo watershed, observed that the areas occupied by koris and surface waters also increased, from 0.02% to 0.79% and from 0.11% to 0.18% respectively. While it is clear that the upstream water bodies in the Birnin Lokoyo [11] and Koléfo [12] sectors were flowing out and migrated towards lower areas further downstream, those of the Awa Data sub-basin are located further upstream than at the outlet: the fossil valley of Dallol Maouri (**Figure 1**; **Figure 3**). Regarding this situation in the kori Goubé catchment area (Tillabéry region), [44] speaks of "connection of the lateral ravines to the main kori pond by the plunging of large sandy alluvial fans responsible for shallow lock ponds". Thus, when the destruction of CT3 outcrops intensifies on all slopes (South, North and Northwest), the sand borrowings from the NW-SE ravines reach the minor bed at the confluences with Bouzouzou and Awa Data from the Southeast (**Figure 11(C)**) and with Dangari, Angoual Houri and Kwara from the Northwest (**Figure 3**). In the mini Kwara basin (**Figure 3**; **Figure 15(A)**), it is considered that significant quantities of sand were recovered in the NW and deposited in the SE (Kwara pond) over periods by the secondary Kwara kori. Therefore, filling in Kwara would impose a low slope on the main kori so that it would negatively impact the development of a permanent body of water at the Dallol Maouri level. Thus, despite its position as the main outlet connected to the Dallol Maouri, the Kwara pond is deteriorating and disappearing from the landscape of the Awa Data sub-basin.

Looking at the height of Dallol Maouri and along the main kori of Awa Data, we can see that the Google images show a mosaic of "S" shaped structures (**Figure 2**; **Figure 3** and **Figure 9(A)**). This state of structures could be due to collapse lowlands, themselves caused in the case of the Iullemmeden syncline-shaped basin (3˚E and 4˚E) by the post-Oligocene compression phase [19]. According to [19], the NE-SW trending Oligocene extension affecting CT3 deposits promotes normal movement of NW-SE to NNW-SSE trending faults and strike-slip activation of NNW-SSE and ENE-WSW trending faults. In both cases, flash floods, and therefore the overflow waters from the permanent Awa Data pond upstream (**Figure 10(B)**), represent a permanent risk of flooding for the populations of the region. As [44] so aptly pointed out, "the alluvial fan phenomenon not only promotes the rapid emptying of ponds, but it also causes their fragmentation into small compartments with low storage capacity" (**Figure 11(C)**).

4.2. Key Challenges and Opportunities Related to Environmental Transformations in Awa Data

Climate variability, when associated with social conditions (e.g., accelerated population growth, low economic productivity, undiversified production, political conflicts and crises, intercommunal violence, violent extremism, etc.), exacerbates existing social and environmental problems [45]. Some would say that humanity has somehow become a "force of nature", a full-fledged actor in global processes and balances [46]. This is to remind us that the increased exposure of soils is not only the main anthropogenic cause of deforestation highlighted by this survey, but that it has had considerable impacts on soil stability. Specifically, in the Awa Data sub-basin, the horizontal and vertical widening of gullies, the silting up of low-lying areas, crop destruction, and the risk of flooding are among the most significant, complex, and interconnected processes, making them the most frequently cited. Soil erosion (water and wind), both climatic and anthropogenic, is thus identified as the primary challenge for the local population.

From then on, gully erosion is one of the manifestations of water erosion that causes soil degradation and significant damage to the environment and human infrastructure [47]. Therefore, such a process manifests itself by the stripping of plateaus, slope sides and in ravines, then the transport and deposition of the torn-off particles to the lowlands, often creating "large sandy alluvial cones" in the ponds [12, 44, 48]. Thus, in the Nigerien part of the Lake Chad basin, the work of [49] highlighted the role of accelerated gully erosion in the silting up of depression areas. According these authors, the total lengths of the gullies, which were nearly one (1) km in 1957 and increased fifteenfold in 2015, confirm this. While these depressions (low-lying areas and interdune basins [50] not only constitute natural resources that support the agro-sylvo-pastoral production of the area, but are also sources of food production and income for local populations [51]. Similarly, [11] showed in the Birni Lokoyo basin (**Figure 1**) that the extraction of local materials on the banks partially clears the beds of water streams and accelerates the phenomenon of water erosion, in addition to promoting wind deflation in the dry season. In the Koléfo basin (**Figure 1**), [12] argued not only that the fields of crops are increasingly exposed to the undermining of the banks of the koris, but cereal crops are not spared from the phenomena of areal erosion (facilitated by the large ravines and tracks on the slopes) and suffocation by sand.

These phenomena, while indicative of agricultural land degradation, offer a range of opportunities that local communities can seize in their adaptation process. In any case, the results establish that the increase in water bodies (widened irrigation ditches, collapsed lowlands, and ponds) is one of the illustrative elements of a major transformation of the landscape in the Awa Data sub-basin. Surface water bodies, such as semi-permanent and permanent ponds, can therefore constitute a valuable resource in a Sahelian context marked by aridity [52, 53]. For a growing number of producers, these waters represent a key to off-season vegetable crops, watering livestock, and even income-generating activities such as artisanal fishing. Furthermore, the numerous visible changes in the Awa Data watershed can foster collective awareness of degradation dynamics, thereby encouraging the emergence of community initiatives for water management and land restoration (**Figure 14, Figure 15**). The sole strategic priority is combating climate change [52].

However, these opportunities cannot be fully realized without a rigorous consideration of the challenges they present. Indeed, bodies of water resulting from runoff are often temporary and can pose health risks. The overuse of pesticides and fertilizers in market gardening, as well as the lack of training and the significant mobilization of wood for fencing, also present major challenges for the environment and human health [8, 25, 42]. Furthermore, the expansion of these wetlands sometimes occurs at the expense of arable farmland, reducing the land available for food crops. Bodies of water can also exacerbate both land disputes and land-use conflicts between interest groups (farmers, ranchers). Indeed, just as the proliferation of tracks in the land modifies certain parameters of soil competence and runoff, the physical nature of bodies of water affects both the degree of mobility of humans and livestock [12]. Regarding rural land, [54] has already observed that "a field cultivated by a single head of household in the 1960s is now cultivated by at least 15 heads of household, resulting in a production that is clearly insufficient to feed the population". Subsequently, the same author pointed out that "the fields have consequently become the subject of disputes and quarrels among the descendants of the original owners". For [48], the lack of infrastructure or controlled drainage systems also exacerbates the vulnerability of communities (even the most remote rural ones) to hazards. Ultimately, the dynamics of water body expansion in the Awa Data watershed reflect a reconfiguration of the relationship between societies and the environment. This therefore necessitates new forms of local governance based on anticipation, integrated resource management, and the valorization of traditional knowledge [4, 11].

5. CONCLUSION

The study conducted in the Awa Data (Niger) sub-watershed highlighted the scale and complexity of phenomena linked to climate and environmental changes, and anthropogenic pressures, within a context of high climate variability. The analysis of land-use dynamics from 1975 to 2025, using geographic information systems and remote sensing, yielded compelling results. The combination of natural factors (e.g. soil type, slope and climate variability) with increasing anthropogenic pressures including deforestation, overgrazing and unsuitable agricultural practices as well as the proliferation of tracks and human mobility accentuate the degradation of land and vegetation cover. This shows that water erosion, favored by irregular and intense rainfall, leads to a loss of arable land, the gullying of banks and beds of secondary watercourses, but also a silting up of lowlands which causes increasingly pearly ponds. Furthermore, the fragility of the catchment area is reflected in the loss of its lowest ponds at the level of its confluence with the Dallol Maouri, filling in of the external downstream areas, thus aggravating the socio-economic impacts on local communities.

In order to effectively combat the phenomena of climate and environmental change and preserve the balance of agricultural land in the watershed, the following actions are recommended: (i) implement more soil and water conservation (SWC) techniques, such as stone bunds, half-moons, benches and erosion control dikes to capture rainwater and reduce runoff and erosion at slopes and (ii) reforest vulnerable areas with trees and shrubs in agricultural and pastoral systems to improve soil fertility, provide shade, fodder and local wood and non-wood products adapted to climatic conditions.

These results show that the perceptions gathered reflect only the male point of view. This male predominance is explained by the socio-cultural and economic realities of the region, where men generally occupy key roles in agricultural operations and land-related decision-making. However, women often play a crucial role in the domestic management of resources and the transmission of traditional knowledge. Their limited participation in this survey may lead to an underrepresentation of these essential dimensions. Therefore, it is important in future research to adopt inclusive strategies aimed at better integrating women's voices in order to obtain a more complete and balanced view of practices. Indeed, excluding women's perspectives on natural resources (e.g., water, firewood) could bias the assessment of human-induced pressures.

CONFLICTS OF INTEREST

The authors reported no conflict of interest regarding the publication of this paper.

ACKNOWLEDGEMENTS

This work could not have been accomplished without the invaluable availability and collaboration of the village chiefs of Awa Data, Angoual Houri, Bouzouzou, Dangari and Tarsossa, who allowed the interviewees to complete the questionnaires throughout the secondary data collection period. A huge thank you to them!

REFERENCES

1. Cellule d'analyse des politiques publiques et d'évaluation de l'action gouvernementale (CAPEG) (2022) Perceptions sur les actions de gestion durable des terres au Niger. Cabinet du premier Ministre, Niamey (Niger), 76 p.

2. Mahe, G., Olivry, J.C. and Servat, E. (2005) Sensibilité des cours d'eau ouest-africains aux changements climatiques et environnementaux: Extrêmes et paradoxes. IAHS Publications, No. 296, 69-177.
3. Traoré, S., Ouattara, K., Ilstedt, U., Schmidt, M., Thiombiano, A., Malmer, A., *et al.* (2015) Effect of Land Degradation on Carbon and Nitrogen Pools in Two Soil Types of a Semi-Arid Landscape in West Africa. *Geoderma*, **241**, 330-338. https://doi.org/10.1016/j.geoderma.2014.11.027
4. Noma Adamou, S., Daoudi, L. and Abdourhamane Touré, A. (2024) Dynamique d'occupation des sols et perception paysanne au Sud-ouest du Niger: Cas du bassin versant du Kori Ouallam. *European Scientific Journal*, *ESJ*, **20**, 163-189. https://doi.org/10.19044/esj.2024.v20n35p163
5. Badiane, A., Sané, B. and Thior, M. (2019) Impacts de la Dynamique des Paysages Agraires sur les Activités Agricoles dans la Commune d'adéane en Basse-Casamance (Sénégal). *European Scientific Journal ESJ*, **15**, 489-506. https://doi.org/10.19044/esj.2019.v15n21p489
6. Yaméogo, J.T., Sanon, Z., Baggnian, I., Somda, I., Somé, A.N. and Axelsen, J.A. (2019) Impact des différents types d'occupation des terres sur la fertilité physique et chimique du sol dans la réserve totale et partielle de Bontioli (Sud-Ouest) du Burkina Faso. *Science et technique*, *Sciences naturelles et appliquées*, **38**, 33-49.
7. INS Institut National de Statistiques (2018) Annuaire statistique régional de Dosso. Direction régionale de l'Institut National de la statistique de Dosso, République du Niger, 153 p.
8. Boubacar Oumarou, R. (2021) Impacts de la pratique du maraichage sur les ressources environnementales dans la commune rurale d'Imanan (Tillabéry, Niger). Master's Thesis, Université de Dosso, 40 p.
9. Boubacar Abou, H. and Dambo, L. (2024) Perceptions paysannes des effets du changement climatique sur la production des cultures pluviales dans la commune rurale d'abala (Region de Tillabéry). *Écho de la Recherche Interdisciplinaire*, No. 3, 111-122.
10. Moussa Issaka, A., Hassane, B., Wagani, I., Abdourhamane Toure, A., Abdoulaye, A. and Garba, Z. (2020) Dynamique hydro-géomorphologique des mares et de l'occupation des sols de 1973 à 2018 dans la commune de Dogonkiria, Dosso. *International Journal of Applied Research*, **6**, 294-300.
11. Issa Saley Balla, F. (2021) Éléments et enjeux de la nouvelle donne climatique et environnementale dans le bassin versant de Birnin Lokoyo (Matankari, Doutchi): Opportunités, défis et perspectives pour les communautés. Master's Thesis, Université de Dosso, 70 p.
12. Issa Kamayé, M.N. (2025) Impacts du changement climatique sur les systèmes d'eau de surface du bassin versant de Koléfo (Nord Doutchi, Niger): Conséquences socio-environnementales. Master's Thesis, Université Abdou Moumouni de Niamey, 77 p.
13. Akoté Allassane, A. (2025) Perceptions sur les Bioindicateurs de la fertilité des terres dans un contexte de changement climatique: cas du transect Bourdami-Koléfou, Nord Dogondoutchi (Niger). Rapport de terrain, Licence Agronomie générale. Faculté d'Agronomie et des sciences de l'environnement. Université Dan Dicko Dankoulodo de Maradi, 50 p.
14. Tiepolo, M., Bacci, M. and Braccio, S. (2018) Multihazard Risk Assessment for Planning with Climate in the Dosso Region, Niger. *Climate*, **6**, Article No. 67. https://doi.org/10.3390/cli6030067
15. Hauswirth, D., Yaye, H., Soumaila, A.S., Djariri, B., Lona, I. and Abba, M.B. (2020) Appui à la formulation concertée de la SPN2A pour la République du Niger: Identification et évaluation des options d'agriculture intelligente face au climat prioritaires pour l'adaptation face aux changements climatiques au Niger (Volume 2: Annexes). Ministère de l'Environnement, de la Salubrité Urbaine et du Développement Durable. Ministère de l'Agriculture et de l'Elevage. Conseil National de l'Environnement pour un Développement Durable. Haut-Commissariat à l'Initiative 3N. AFD. Facilité Adapt'Action. Niamey, Niger. Baastel-BRL-ONFI, 101 p.
16. Katiellou, G.L., Tarchiani, V. and Tiepolo, M. (2021) Risque et adaptation climatique dans la région de Dosso au

Niger. Études Africaines. Série Géographie. L'Harmattan, 297 p.

17. ACBF (2023) Défis et opportunités de coordination pour l'adaptation au climat dans l'agriculture africaine. Fondation pour le renforcement des capacités en Afrique (ACBF). Harare, 28 p.

18. Abdoul-Hayou, H.H., Moustapha, A.M., Issoufou, S. and Halidou, A.H. (2023) Hydrodynamic Characterization of the Water Table of the Upper Dallol Maouri Basin (Niger). *Open Journal of Modern Hydrology*, **13**, 77-93. https://doi.org/10.4236/ojmh.2023.132004

19. Ousmane, H., Hantchi, K.D., Hamidou, L.B., Ali, I.A. and Konaté, M. (2020) Caractérisation de la déformation des dépôts oligocènes du Continental terminal 3 (Ct3) dans la région de Niamey (Bordure Orientale du Craton Ouest Africain, Bassin des Iullemmeden). *European Scientific Journal*, *ESJ*, **16**, 418-441. https://doi.org/10.19044/esj.2020.v16n15p418

20. Yagi, S. (2010) Étude diagnostique de la filière pomme de terre dans les communes de Doutchi, Koré Mairoua et Soukoukoutan (Département de Dogondoutchi). Master's Thesis, Université Abdou Moumouni de Niamey, 88 p.

21. Ozer, P. and Erpicum, M. (1995) Méthodologie pour une meilleure représentation spatiotemporelle des fluctuations pluviométriques observées au Niger depuis 1905. *Sécheresse*, **1**, 103-108.

22. Greigert, J. (1966) Description des formations crétacées et tertiaires du bassin des Iullemmeden (Afrique occidentale). BRGM ed., 229 p.

23. Hantchi, K.D., Hassane, B., Ousmane, H., Balla, F.I.S., Konaté, M. and Garba, Z. (2022) Dynamics and Vulnerability of Hydrogeomorphological Units to the Degradation of Climatic Conditions in the Watershed of the Birnin Lokoyo Pond (Iullemmeden Basin, Southwestern Niger). *Journal of Environmental Protection*, **13**, 233-260. https://doi.org/10.4236/jep.2022.132015

24. Laouali, I.K. and Konaté, M. (2019) Extraction de réseaux de fractures en milieu sédimentaire par les techniques de la télédétection intégrant une analyse statistique et structurale: Cas des formations mésocénozoïques du bassin des Iullemmeden, Niger Central. *Afrique SCIENCE*, **15**, 39-53.

25. ONG RAIL (2019) Étude de faisabilié des aménagements des sites maraichers dans le département de Dogondoutchi. Commune de Dogondoutchi, 97 p.

26. INS (2018) Annuaire statistique régional de Dosso. Direction régionale de l'Institut National de la statistique de Dosso. 153 p.

27. CRM (2017) Commune Rurale de Matankari. Plan du Développement Communal 2017-2021, 115 p.

28. CRS (2021) Commune Rurale de Soucoucoutane. Plan de développement communal (PDC) de la commune rurale de Soucoucoutane 2018-2022, 134 p.

29. Hillion, A., Boucher, J.M. and Roux, C. (1989) Le traitement des images de télédétection: Aperçus et perspectives. Télédection en francophonie. Éd. AUPELF-UREF, John Libbey Eurotext, 97-110.

30. Wulder, M.A., Loveland, T.R., Roy, D.P., Crawford, C.J., Masek, J.G., Woodcock, C.E., *et al.* (2019) Current Status of Landsat Program, Science, and Applications. *Remote Sensing of Environment*, **225**, 127-147. https://doi.org/10.1016/j.rse.2019.02.015

31. Bweya, M.N., Musavandalo, M.C. and Sahani, M. (2019) Analyse de la dynamique spatio-temporelle du paysage forestier de la région de Beni (Nord-Kivu, RDC). *Geo-Eco-Trop*, **43**, 171-184.

32. Hantchi, K.D., Issaka, A.M., Hassane, B., Ibrahim, M.B., Ousmane, C.S., Lawali, S., *et al.* (2024) Open-Air Quarries in the Urban Commune of Zinder (South-East Niger): An Opportunity with Strong Externalities. *Geomaterials*, **14**, 59-81. https://doi.org/10.4236/gm.2024.144005

33. Ndi Roland, A. and Wang Afo'o, C.P. (2024) Cultures maraichères et conséquences environnementales dans l'Arrondissement de NKOLAFAMBA, Région du Centre-Cameroon. *Revue Espace Géographique et Société Marocaine*, **83**, 167-191.

34. Gomis, C. (2025) Dynamiques spatio-temporelles des formes d'occupation du sol dans le bassin de la Moyenne Casamance au prisme des changements climatiques. *African Scientific Journal*, **3**, 1178-1200.
35. Moussa Ibrahim, B., Abdou Moussa, M., Warzagan Aghali, I., Na-Allah Abdoulaye, B., Ibrahim Mahamadou, B., Ibrahim, M., *et al*. (2020) Dynamique Hydro-Erosive Actuelle Des Bassins Versants Endoreiques De La Region De Niamey (Sud-Ouest Du Niger). *European Scientific Journal*, *ESJ*, **16**, 149-168. https://doi.org/10.19044/esj.2020.v16n33p149
36. Touré, A.A., Guillon, R., Garba, Z., Petit, C., Bichet, V., Durand, A. and Sebag, D. (2010) Évolution des paysages Sahélines au cours des six dernières décennies dans la région de Niamey: De la disparition de la brousse tigrée à l'encroutement de surface des sols. *Pangea*, **5**, 35-40.
37. Cappelaere, B., Descroix, L., Lebel, T., Boulain, N., Ramier, D., Laurent, J., *et al*. (2009) The AMMA-CATCH Experiment in the Cultivated Sahelian Area of South-West Niger—Investigating Water Cycle Response to a Fluctuating Climate and Changing Environment. *Journal of Hydrology*, **375**, 34-51. https://doi.org/10.1016/j.jhydrol.2009.06.021
38. Moussa Abdou, O., Rabiou H., Soumana I. and Dan Guimbo I. (2024) Étude de la dynamique de l'occupation du sol dans la commune de Tondikiwindi dans l'ouest-nigérien. *AFRIMED AJ-Al Awamia*, **145**, 49-59.
39. Leblanc, M.J., Favreau, G., Massuel, S., Tweed, S.O., Loireau, M. and Cappelaere, B. (2008) Land Clearance and Hydrological Change in the Sahel: SW Niger. *Global and Planetary Change*, **61**, 135-150. https://doi.org/10.1016/j.gloplacha.2007.08.011
40. Bouzou, M.I. (2000) Réponses géomorphologiques à la problématique de la conservation des eaux et des sols au Niger. Rapport de synthèse HDR, Institut de Géographie Alpine, Université Joseph Fourier, Grenoble 1, 193 p.
41. Moussa Issaka, A. (2014) Dynamiques érosives et des états de surface dans la partie nigérienne du lac Tchad. Thèse de Doctorat, Université Abdou Moumouni, 156 p.
42. Seydou Oudou, M. (2020) Perceptions paysannes de l'impact des pratiques agricoles sur les ressources environnementales (sols, eaux, végétation): Cas du périmètre irrigué de Djiratawa (Maradi, Niger). Mémoire de Licence EIE, Université Dan Dicko Dankoulodo de Maradi, 58 p.
43. Favreau, G. (2000) Caractérisation et modélisation d'une nappe phréatique en hausse au Sahel: Dynamique et géochimie de la dépression piézométrique naturelle du kori de Dantiandou (sud-ouest du Niger). Thèse Doctorat Sciences de la Terre, Université Paris-Sud 11, 348 p.
44. Moussa, M.S. (2006) SIG et dynamique de l'occupation du sol du bassin versant du kori Goubé dans le degré carré de Niamey. Mémoire DEA Géographie, Université Abdou Moumouni de Niamey, 74 p.
45. Van Ackern, P. and Adrien Detges, A. (2022) Changement climatique, vulnérabilité et sécurité au Sahel. Trois scénarios pour le Burkina Faso, le Mali et le Niger à l'horizon 2050. Projet Cascades, Adelphi. European's Union Horizon 2020 Research and Innovation Programme, 18 p.
46. CNEDD (2011) Conseil National de l'Environnement pour un Développement Durable (CNEDD), Impacts des changements climatiques dans le secteur de l'énergie au Niger, Rapport final. Cabinet du Premier Ministre, 46 p.
47. Abba, B. (2021) Risques environnementaux liés aux eaux pluviales sur le site de Wacha (région de Zinder). In *Revue Ahoho*, Laboratoire Lardymes, Université de Lomé (Togo), Vol. 26, 191-202.
48. Maazou, A. (2017) Étude technique portant sur «la caractérisation des koris» dans les communes d'Ajekoria, Dakoro et Korahane. Projet «Régionalisation de l'Adaptation à Base communautaire au Niger» (ABC-Maradi). Cabinet du Premier Ministre, 60 p.
49. Moussa Issaka, A., Abdourhamane Toure, A., Hassane, B. and Garba, Z. (2018) Dynamique du ravinement en milieu dunaire dans la partie nigériennedu bassin du Tchad. *Geo-Eco-Trop*, **42**, 337-342.
50. Ambouta Karimou, J.M., Zabeirou, T., Guéro, M. and t Amadou, B. (2005) Typologie des cuvettes et bas-fonds et

possibilité d'exploitation agricole et de valorisation. Étude sur l'inventaire et la caractérisation pédologique et hydraulique des cuvettes oasiennes dans le Département de Maïné-Soroa, Projet d'Appui à la Gestion des Ressources Naturelles-PAGRN, DANIDA, Niger, 24 p.

51. Kanembou, L., Malam Assane, M. and Malam Bourna Bagale, M. (2024) Impacts socio-économiques des cultures des cuvettes-oasiennes sur la sécurité alimentaire des populations: Cas de la cuvette de Guirsilik dans la commune de Goudoumaria (Région de Diffa/Sud-Est du Niger). *European Scientific Journal, ESJ*, **20**, 106-121. https://doi.org/10.19044/esj.2024.v20n29p105

52. PNUD et BCPR (2013) Programme des Nations Unies pour le développement (PNUD), Bureau de la prévention des crises et du relèvement (BCPR) 2013. Gestion durable des zones humides face aux risques climatiques au Niger: Le cas de la mare de Tabalak. UNDP BCPR.

53. Adamou, M., Alhou, B., Nazoumou, Y. and Alloke, G. (2015) Impacts des facteurs climatiques et anthropiques sur les ressources et la qualité des eaux de la mare de Tabalak. *International Journal of Biological and Chemical Sciences*, **9**, 1665-1677. https://doi.org/10.4314/ijbcs.v9i3.45

54. Abdourhamane Touré, A. (2011) Érosion en milieu sableux cultivé au Niger: Dynamique actuelle et passée en liaison avec la pression anthropique et les changements climatiques. Ph.D. Thesis, Université de Bourgogne, 224 p.