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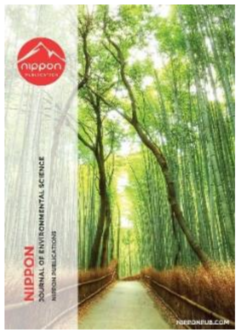

Full Length Research Paper

Analysis of the effects of climate change on pH and salinity of soil in Bakoum valley watershed (Sedhiou Region/Senegal)

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Abstract. In Senegal, the effects of climate change have led to increased salinization, acidification and silting of arable land. Agricultural land management using geomatics tools has become essential for sustainable agriculture. The aim of this study is to determine the impact of salinization, acidification and siltation in the valley of the Bakoum watershed. For this purpose, Aster images (MNT) with a resolution of 30 m were used. This operation was followed by the taking of GPS points in the study area in order to geolocate the infrastructures and delimit the areas lost by the degradation phenomena. A total of 36 soil samples were taken, including 24 samples at depths of 0-20 cm and 20-40 cm in 2015; and 12 samples at depths of 0-20 cm and 20-40 cm in 2017. They were analysed in the laboratory to assess electrical conductivity and pH in 2015 and 2017. In two years, the salinity of the valley soils varied from 83 to 9540 µohm in 2015 and from 20 to 7440 µohm in 2017. Acidity (pH) ranged from 3.6 to 4.2 in 2015 and 3.16 to 4.8 in 2017. The area lost due to salinity, acidity and silting is estimated at 31 ha, i.e. 0.74% of the valley area. These results show that urgent measures must be taken to better exploit the valley's rice-growing potential and thus contribute to the revival of rice-growing activities in the region.

Keywords: Agricultural, *Bakoum*, Climate change, Salinity, Senegal

1. INTRODUCTION

Casamance was considered the "granary of Senegal" (Sané, 2017). Agriculture forms the basis of the economy of the Sédhiou region. More than 80% of the region's population practices agriculture. It provides more than 90% of the income and plays an important role in feeding the population. The cultivable area is 208,050 hectares, of which 36,111 hectares are suitable for rice cultivation (ANSD, 2013), with a contribution of 4,170 hectares from the Bakoum Watershed. However, for several decades, increasingly unfavourable climatic, environmental and socio-economic conditions have led to a decline in production and the reduction and/or abandonment of agricultural land.

Thus, the elaboration of multiple agricultural development programmes initiated in Casamance by different development actors (USAID, PRIMOCA, SOMIVAC, etc.) with more or less mitigated results (Manga, 2003). In addition, Senegal, through its Projet “Pôle de Développement de la Casamance” (PPDC), rehabilitated an anti-salt dam in the Bakoum watershed valley in 2017. The aim of this dike was to participate in the looking for solutions to the problems (salinisation, acidification and silting) linked to the agricultural development of the Bakoum watershed and to contribute to better management of this area, under the effects of climate and anthropogenic factors.

The persistent drought that has affected Sahelian countries since 1968 has had a negative impact on agriculture and the rural economy. Senegal, which is located in the Sudano-Sahelian zone, has suffered the same effects. The degradation of agricultural land is one of the notable phenomena of the rainfall deficit. Anthropogenic factors were often the accelerator of this degradation of the natural environment (Touré, 2011). Given this situation, the necessity of managing and restoring degraded land in Casamance became essential. Although very rich, the Casamance environment is still fragile. If solutions are not found, the process of very rapid degradation is likely to be difficult to irreversible (Manzelli et al., 2015). The problem of agricultural development in Casamance, and more particularly in the Bakoum watershed, is still problematic. The strategies adopted by the actors have not yet found a solution to the demands of the farming population. Thus, several development aid actions have been undertaken to support the recovery of degraded soils in Bakoum. Among the interventions in the development of this watershed, we can note that of the Rural Project "Integral Development of Middle Casamance" (PRIMOCA), financed by the Italian cooperation and the Government of Senegal from the end of the 1980's. The project is based on the "Integral Development of the Middle Casamance" (PRIMOCA), a rural project financed by the Italian cooperation and the Government of Senegal. In addition to this project, the action of the National Institute of Pedology (INP) through the amendment of compost, the fight against water erosion and soil phosphating has also been noted in the area. Despite the strategies implemented, the catchment area is still facing problems of environmental degradation, loss of surface areas through salinization, acidification and silting. In addition to this, we note a lack of mapping of the basin and its valley, as well as the works carried out in the area. This work aims was to contribute of improved land management in the Bakoum Watershed.

2. MATERIALS AND METHODS

2.1. The geographical location of the study area

The Bakoum Watershed is located in the northern hemisphere. Administratively, it borders on three Communes which are: The Communes of Sédhiou, Diendé and Bambali, in the Department of Sédhiou. It has a surface area of about 4170 hectares (Figure 1).

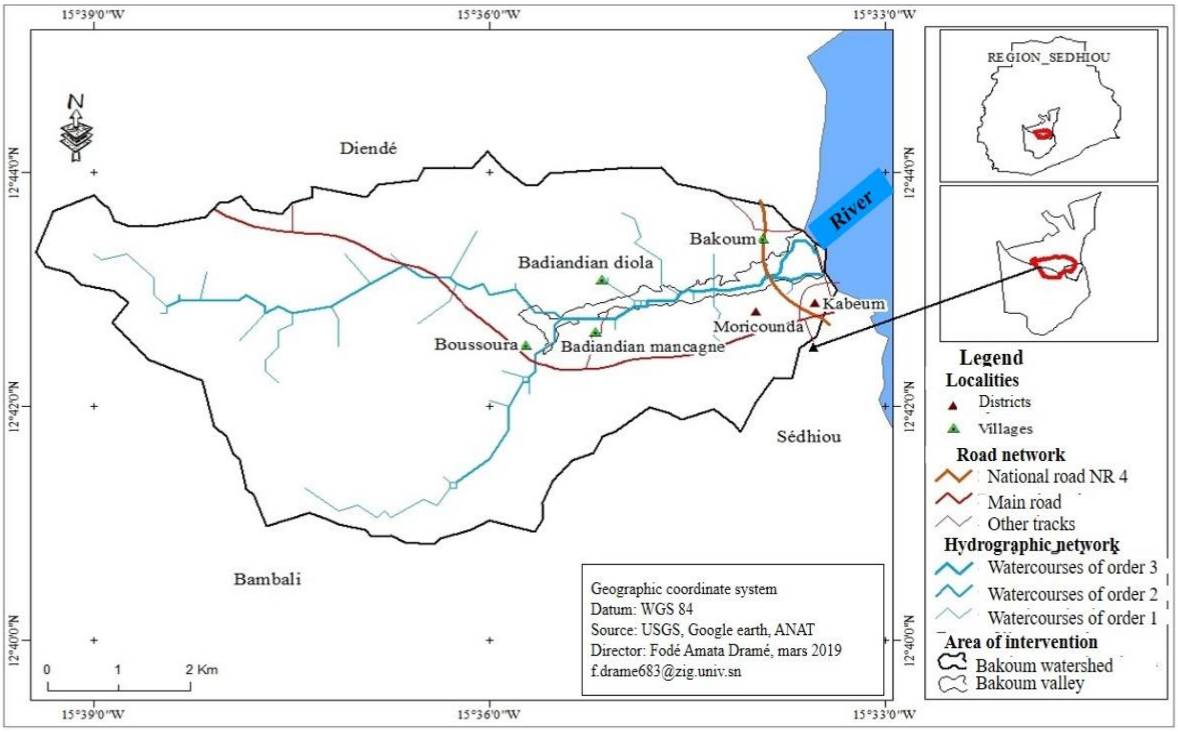

Figure 1. Geographical location of the Bakoum Watershed in 2019

2.2. The rainfall situation in the Sédhiou region from 1951 to 2019

The analysis of the rainfall situation in the Sédhiou region between 1951 and 2019 through the stations of Bounkiling, Diattacounda, Diendé, Dianamalary, Djirédji, Sédhiou and Marsassoum made it possible to identify three important periods. The first period (1951 to 1967) is characterized by abundant rainfall with alternating wet years. Between 1967 and 2000, the region experienced a rainfall deficit marked by dry years. From 2000 onwards, a gradual return of rainfall is observed, marked by rainfall instabilities. The general rainfall tendency is tending to decrease (Figure 2).

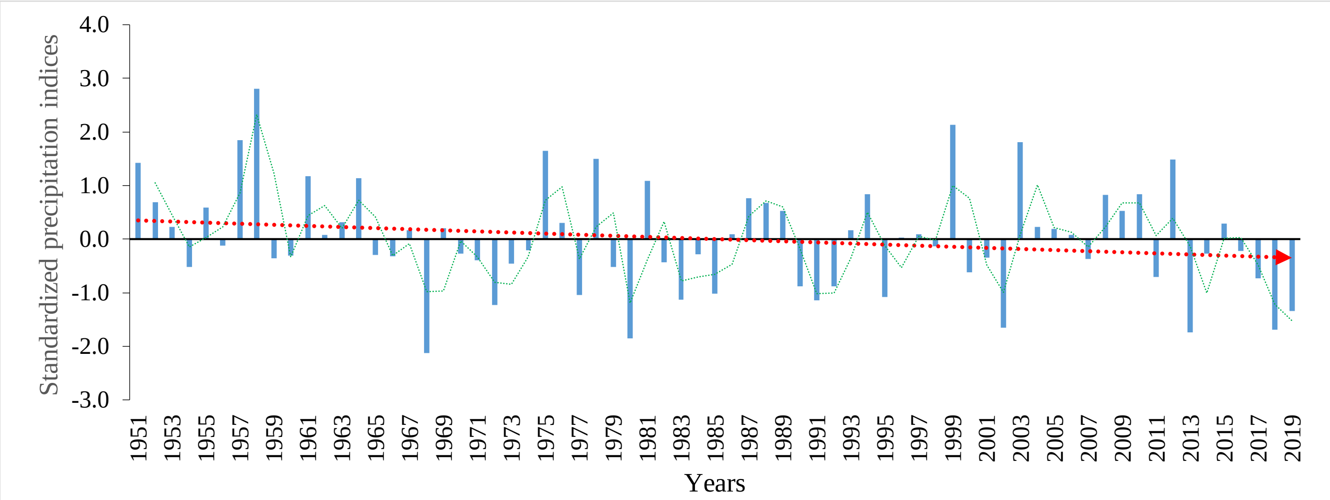

Figure 2. Summaries of standardized rainfall anomalies in the Sédhiou region between 1951 and 2019 (Source: ANACIM, 2019)

2.3. Soil Sample Collection

Soil samples were taken in 2015 and 2017. For 2015, the samples were taken according to the salinity gradient. Thus a transect perpendicular to the river was set up (Figure 3). On this transect, points equidistant from 100 m materialize the points where soil samples were taken. Soil samples were taken at a maximum depth likely to be reached by the roots of the rice, with soil samples taken at 0-20 cm and 20-40 cm. Each sample is referenced (date of sampling, location, depth, agricultural zone). The geolocation of each point is carried out on the basis of their geographical coordinates obtained using GPS (INP, 2015). The same method will be used in 2017. However, in 2017, the points were selected randomly and the depth of the soil sampling points is 50 cm, i.e. 0-20 cm and 20-40 cm.

2.4. Geomatics approach

Geomatics is a discipline concerned with the management of spatially referenced data through the integration of sciences and technologies related to their acquisition, storage, processing and dissemination (Peagelow, 2004). In order to do this, we used certain structures such as the Agence Nationale de l'Aménagement du Territoire du Sénégal (ANAT) for Senegal's administrative "shape files". In addition, GPS points in the study area were taken in order to geolocate infrastructures and delimit areas lost by degradation processes. Platforms were used to download satellite images. These are image (DTM) and Google earth images. The resolution of the Aster image (DTM) is 30 m, covering 99% of the surface of the globe, with NASA (National Aeronautics and Space Administration) as editor (https://asterweb.jpl.nasa.gov, https://fr.mwikipedia.org). Most google earth images have a resolution of more or less 3m.

Figure 3. Soil sampling device

Unsalted points
Salted points
Transect
Potentially salty area

2.5. Data processing

The pH and electrical conductivity (2017) were analyzed at the Chemistry and Physics of Materials Laboratory of the Assane Seck University in Ziguinchor. Soil pH values were interpreted using the soil series legend proposed by the National Institute of Pedology (Doucet, 2006). The analysis of the degree of salinity of the soils was based on the interpretation of their electrical conductivity (EC) according to the standards of Durand (Bocoum, 2004). The satellite data were processed with Arc gis 10.5 software. For the spatial analysis (identification of areas occupied by salt, acidity and sand, and also the location of structures), we used field data. The Aster image (MNT) used enabled us to characterize the watershed area (its delimitation: watershed area limit, its relief, its slope and its hydrographic network). The limit of the watershed valley is obtained by digitizing the Google earth image after it is geo-referenced. A few GPS bridges were used for reference and verification.

3. RESULTS AND DISCUSSION

3.1. Characterization of the Bakhoum watershed area

This study identified two types of structures: so-called point structures and linear structures (Figure 4a).

For point infrastructures, these are:

- A bridge built on the salt dike downstream of the basin;
- Three gates bridges, two of them are built on the RN4 and one on the lateritic cordon upstream of the catchment area;
- A passage in the form of a bridge known as the sluice gate of the anti-salt dike.

Concerning the linear structures, these are:

- The salt dam was built in the late 1980s by PRIMOCA and repaired by PPDC in 2017. The aim is to slow down salt intrusion, the main cause of salinisation and acidification.
- The national road (RN4), is not planned in the development of the Watershed. However, it has disturbed the natural functioning of the watershed. It provides a link between the Commune of Sédhiou and that of Diendé.
- The lateritic cordon is identical to the RN4. It provides access between the Commune of Sédhiou and the Village of Badiandian Diola.

The altitude varies from 4m to 61m in the geographical space of the Bakoum watershed. The low altitudes (4 to 23m) are located in the East of the Basin. It is in this part that almost all the different localities are located. As for the high altitudes (42 to 61m), we find them more precisely in the West of our study area. It is to the North and South that we have the middle altitudes (23 to 42m) (Figure 4b).

The Bakoum slopes are relatively low. They are generally between 0 and 14% (Figure 4c).

Three soil types are identified in the Bakoum area (Figure 4d), whose characteristics are described below. These are:

- Ferralitic soils are red soils that are very rich in iron oxides and alumina oxides. These soils are formed under forest cover and in tropical or equatorial climates. Indeed, the Bakoum Watershed is under plant cover and is located in the tropical zone.
- Hydromorphic soils or grey soils are located at the bottom of the slopes. The hydromorphic soils in Salty Gley are derived from the fluviomarine alluvial contact and border the Casamance River and the Soungrou. They are very clayey soils, poor in organic matter and with a massive structure. Difficult to work, they are suitable for rice growing.
- Poorly evolved soils are young soils that are characterized by low mineral alteration and low organic matter content, which is generally superimposed on the mineral substrate without forming an organo-mineral complex. These soils have various origins linked to the climate, erosion or external inputs.

3.2. Environmental Impacts

Soil samples were taken from the Bakoum Watershed valley. They were then measured in laboratory to determine electrical conductivity (EC) and acidity (pH) (Table 1 and Table 2).

Table 1. EC Soil and Water Reference Scale (INP, 2015)

	From	To	Water/Soil
	Egale	250	Low Salinity
	250	750	Average Salinity
	750	2250	High salinity

CE (µohm)	2250	5000	Very high salinity
	>5000		Excessively salty

Table 2. Soil and water pH reference scale (INP, 2015)

	From	*To*	Water and Soil
pH		< 4.5	Extremely acidic water
	4,6	5,2	Very acidic
	5,3	5,5	Acidic
	5,6	6	Moderately acidic
	6,1	6,6	Slightly acidic
	6,7	7,2	Neutral
	7,3	7,9	Slightly alkaline
	8	8,7	Alkaline
	>8.5		Very alkaline

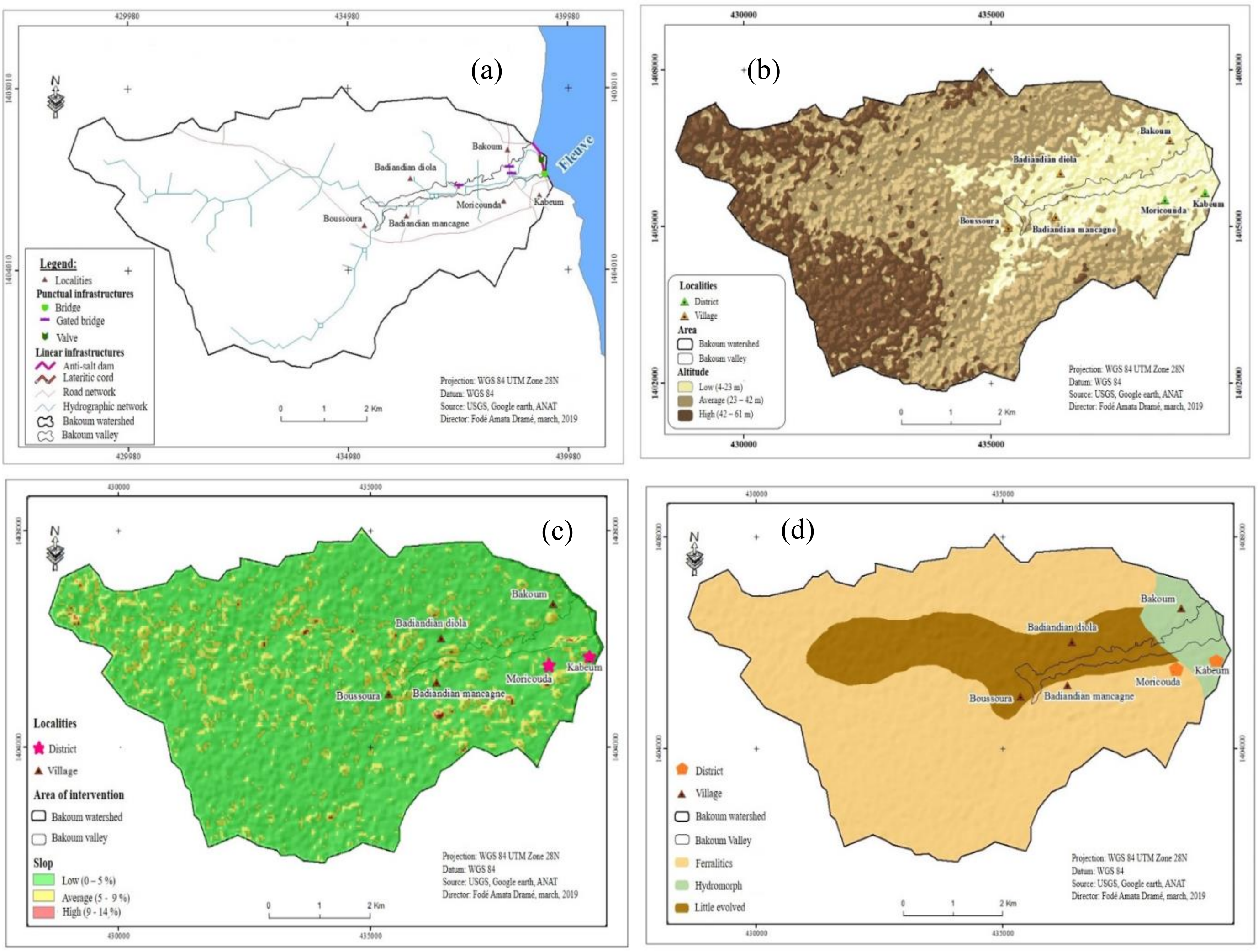

Figure 4. Characteristics of the Bakhoum Valley: (a) = hydro-agricultural developments, (b) = relief, (c) = slope, (d) = soil types

3.3. Gradient of salinity Analysis: Electrical Conductivity (EC) in µS/Cm in 2015 and 2017

Electrical conductivity is used to calculate the ability of a material to conduct electricity. Water that contains mineral salts has an EC (Taillet et al., 2013). The results presented on the map above constitute the reference situation of the salinisation of the Bakoum Valley in 2015.

The EC limit for determining salinization is 500 µohm (Table 1). Above this limit, low to very high salinization is observed. In the Bakum Valley, salinisation is marked at the first (anti-salt) dyke located on the river up to a distance of 600 m inside the valley. It is from point 5 onwards that salinisation is no longer observed.

The results of EC 2017 show a decrease in salinity in Bakoum (Figure 5). In 2015, the biggest decrease in salinity went from 9540 µohm to 7440 µohm in 2017. It is from the third point onwards that the presence of salt is no longer observed. In fact, in 2017, certain decisions were taken in the context of watershed development, such as the rehabilitation of the salt dam.

In Bakoum, as in most catchment areas in Senegal, the problems that have made agricultural development difficult since the drought of the 1970s are natural and man-made. These problems include land degradation (through salinization, acidification and water erosion leading to silting), habitat extension, lack of management of hydro-agricultural structures, unsuitable farming techniques, and seawater intrusion (Ndiaye et al., 2015). These phenomena are detrimental to the environment and socio-economic activities. Their control is sometimes very difficult, if not impossible, which often calls into question the many measures taken. This is the case in the Bakoum Valley, where salinization, acidification and silting combined with anthropogenic effects are a constant concern for the agricultural population and development stakeholders, despite all the strategies developed.

According to Manzelli et al. (2015), the factors that limit the efforts of agricultural development actors in the Sédhiou region are related to nature and human activities. Salinisation by the advance of salinity in the Bakoum watershed is estimated at 9540 µohm highest in 2015 (INP, 2015) and 7440 µohm highest in 2017. This is well above the critical threshold of resistance of rice (*Oryza sativa* L.) to saline stress, which has been estimated at 3000 µS/cm by Zongo (Zongo, 2014). Although there was a decrease in salinization between these two years, it remained excessive until 2017. The consequences of this decrease are a drop in rice productivity, a drop in water quality and a reduction in the area sown.

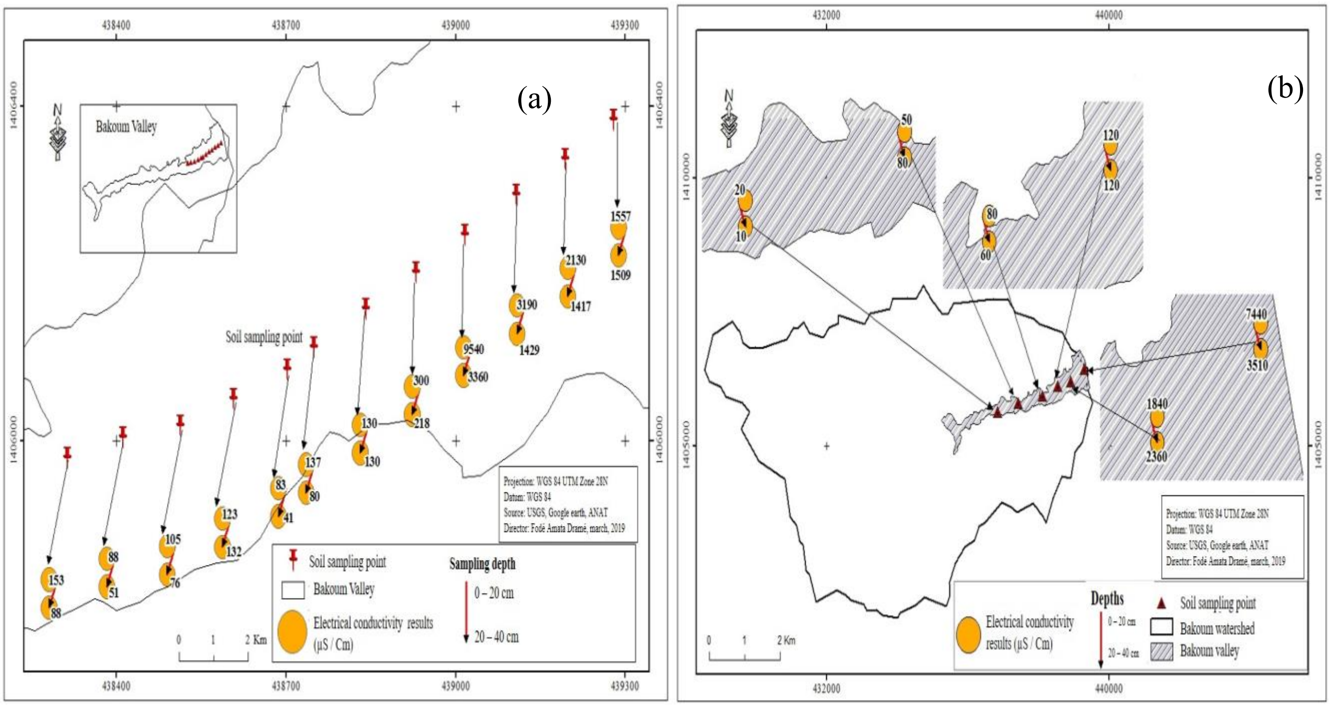

Figure 5. Gradient of salinity in the Bakoum Valley in 2015 = (a) and 2017 = (b)

3.4. Gradient of acidity analysis (pH) in the Bakoum valley in 2015 and 2017

Hydrogen potential pH is a measure of the chemical activity of hydrons in solution. More often, pH is a measure of acidity. The limit of pH for determining acidity is 6.6 according to our reference (Table 2).

Below this standard, moderate and extreme acidity is observed. In 2015, the Bakoum valley is marked by a very acidic to extremely acidic acidity. The pH varies from 3.6 to 4.8 (Figure 6 (a)). Until 2017, the pH of the Bakoum Valley varies from very acid to extremely acid. Indeed, the pH ranges from 3.16 to 4.8 (Figure 6 (b)).

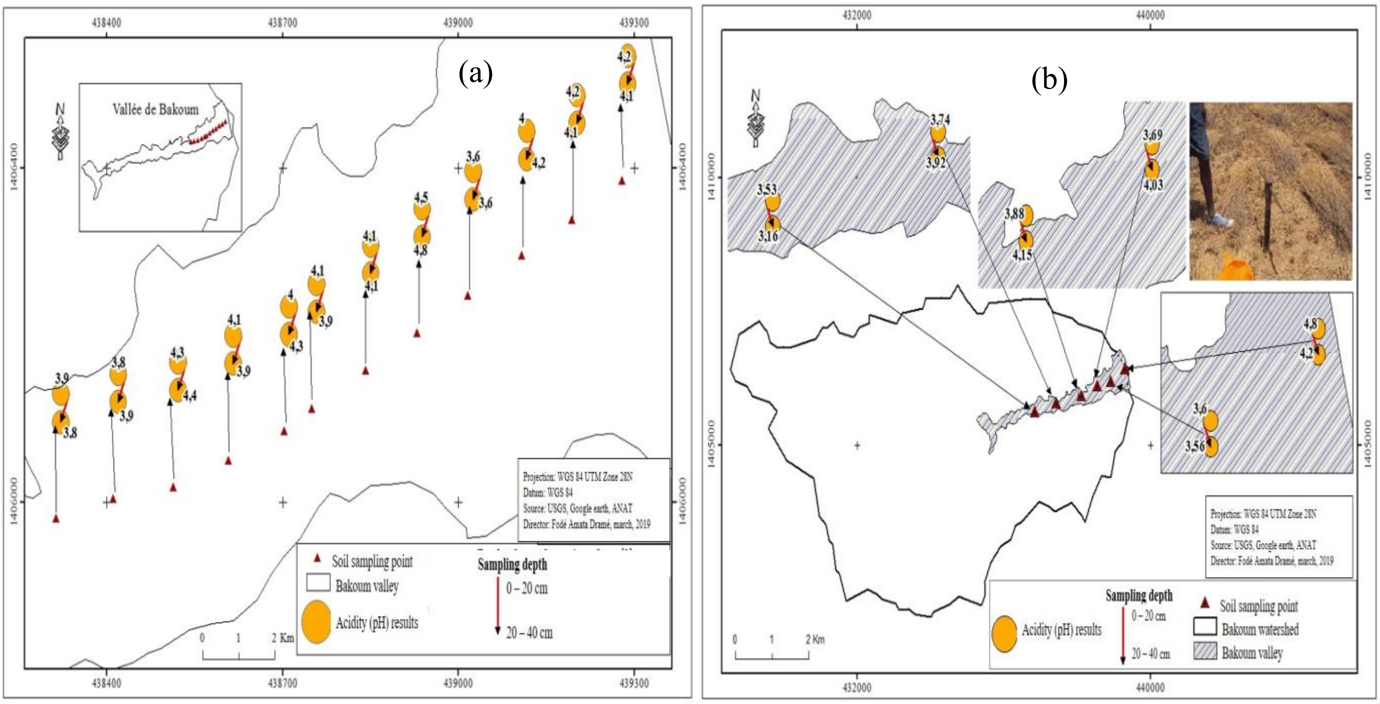

Figure 6. Gradient of acidity in the Bakoum Valley in 2015 = (a) and 2017 = (b)

Acidification is also present in this area at the valley level. Soil pH plays an important role in the availability of nutrients for crops (Dinon and Gerstmans, 2008). This acidification of cropping areas especially at valley level has been raised by several authors (Diallo et al., 2015; Dasylva et al., 2019). It is caused by rainfall deficit, groundwater recharge, sulphide oxidation (Duchaufour, 1983; FAO, 1998). These phenomena in turn cause degradation of mangroves, abandonment of rice fields, etc. (Duchaufour, 1983; FAO, 1998). From 2015 to 2017, the pH of the Bakoum Valley varies from very acidic to extremely acidic. Indeed, a pH ranging from 3.6 to 4.8 in 2015 (INP, 2015) and from 3.16 to 4.8 in 2017 is noted. These results confirm the work of Diallo et al. (2015) who, at the end of their study, noted very high acidity in the market gardening areas in the Niayes zone. In 2019, we were able to assess, thanks to geomatics tools, particularly geographic information systems, the surface lost through salinisation and acidification. It is estimated at 29 hectares (Figure 7).

Silting is induced by the erosive phenomenon and is observed in the catchment area. The consequences are: reduction of the cultivable surface area, transport of inert materials which is at the origin of the reduction in soil fertility, reduction in the efficiency of development works. The area lost in 2019 due to silting is 2 hectares. Anthropic factors are limiting factors in socio-economic actions. These factors include the following:

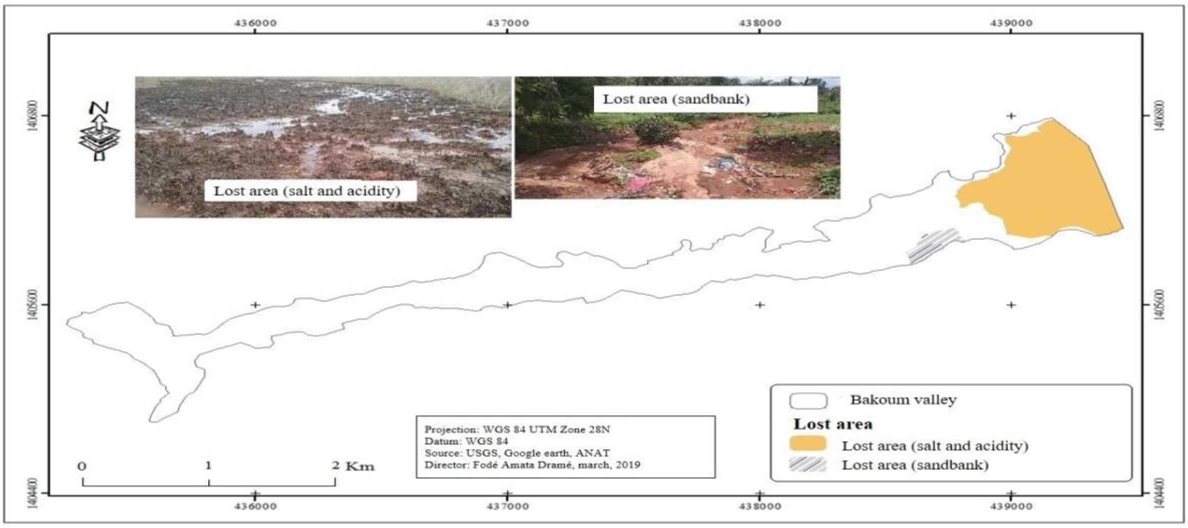

Figure 7. Areas lost due to salinisation, acidification and silting in the Bakoum Valley in 2019

The problem of maintenance of rice protection structures built by state or non-state authorities. This is the case of the anti-salt dam that was built by PRIMOCA in the 1990s to balance the water level and preserve the rice field from salinity. Nevertheless, durability is one of the first problems because of its maintenance cost. It is also the irresponsibility of the beneficiaries. The hydro-agricultural developments that have been carried out in this area have not often met the objective set because of the lack of collaboration of the populations (Dasylva et al., 2019). During the exploratory mission to the Bakoum Valley, the chief of the village of Badiandiang Diola informed that the locks of the structure that regulate the water upstream were stolen by the villagers themselves.

3.3. Impact of salinisation, acidification and silting on the loss of arable area

The impacts of land degradation factors are very real in Baku. The area abandoned in the Baku Valley in 2019 is estimated at 31 hectares (ha). The area lost through salinization and acidification is 29 ha. The area not passable due to silting is estimated at 2 ha (Figure 7). The cutting of wood on the slopes is a phenomenon that favours the silting up of the rice-growing perimeters. In Bakoum itself, the situation is very present and visible. In the Diendé (PLD, 2012), the problem of social organization in relation to plastic waste management. The latter reach the rice plots via runoff water, preventing plants from growing. Among other anthropic factors, which limit the actions of agricultural planners is the lack of certified seeds adapted to current climate changes, etc.

4. CONCLUSION

The improvement of agricultural production in general and rice production in particular is one of the major aims of agricultural practice. However, this objective cannot be achieved without good control and in-depth knowledge of the constraints linked to agricultural development. In Senegal, as everywhere else in the world, these constraints are natural but also socio-economic. Most of the measures taken or strategies developed have not yielded the expected results. In Bakoum, the situation is the same. So geomatics was chosen to detect, understand and explain the real causes of this phenomenon. In addition to this, to quantify the damage in the Bakoum Watershed. The use of geomatics has enabled us to visualise the infrastructures built in the Bakoum Watershed, to determine and evaluate the areas affected and lost through salinisation, acidification and silting, thanks to the analysis of soil samples and fieldwork. In 2019, the results of the study show that 31 hectares of land are abandoned in the watershed by this problem, of which 29 hectares are affected by salinization and acidification and 2 hectares by silting.

In this regard, we put forward the idea that this study can be improved with the use of more parameters such as good quality satellite images and the implementation of sustainable, integrated and participatory management strategies by all stakeholders.

Conflict of Interest: We declare that there is no conflict of interest.

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