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Spatio-temporal dynamics of agricultural and built-up areas in the Niaye area of Pikine urban wetland (Dakar, Senegal)

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ABSTRACT

The Niaye area of Pikine, a wetland with favorable physical and climatic conditions, is a rich and varied ecosystem that guarantees a supply of water and fertile soil, conducive to market gardening. This plays an important socio-economic role in the Dakar region. However, this sensitive and fragile ecosystem is often affected by poor farming practices. The aim of the study was to analyze the spatial evolution of agricultural areas and built-up areas in order to identify related environmental problems. Interview guides, aerial photographs from 1966 and 1978 and Digital Globe Over view 2 satellite images from 2004 and 2022 were used. The interview guides were used to obtain data on the management of the market gardening activity, and also to identify the environmental problems it generates. Satellite data processing revealed, through cartographic analysis, a progressive market gardening dynamic of +5.07%. In addition, the built-up area around the lake has increased by over 200%, resulting in a 68.4% decline in upland vegetation and a migration of market gardeners to the lake. This situation leads to the destruction of market garden crops in the rainy season as the water rises. What's more, the intensification of market gardening in response to the population's growing demand for vegetables has not failed to encourage bad practices, including the use of pesticides and sewage, which is a public health problem and a threat to the future of this wetland.

Keywords: Socio-spatial dynamics, wetland, market gardening, Niaye Pikine.

INTRODUCTION

Wetlands are among the richest ecosystems in terms of biodiversity, providing numerous services. They represent the most productive ecosystems on the planet after the rainforest, constituting ecosystems of great ecological and socio-economic value (OZHM, 2012). Wetlands are among the most productive ecosystems on earth, due to the complex interactions between the water, soils, microorganisms, plants and animals that make them up, and the close interdependence they weave with their environment (De Groot et al., 2007). They perform multiple functions, including hydrological (nutrient trapping), climatic (microclimate regulation and carbon storage) and biological (primary and secondary production) (Mitsch and Gosselink, 2000).

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Urban agriculture is a fast-growing economic activity in many of the world's cities, particularly those in developing countries. Comprising a diverse mix of activities, it helps to supply cities with food, particularly fresh produce, and is thus an option for combating poverty. However, market gardening is the most highly developed component of urban agriculture. Today, vegetable farming is part of the African urban environment (Akinbamijo et al., 2002). In this respect, market gardening remains an activity that is highly sensitive to urban dynamics. On the one hand, urban growth increases outlets, and on the other, it accentuates pressure on space (Broutin et al., 2005).

In sub-Saharan Africa, population migration dynamics continue to modify the population structure as a result of rapid urbanization. In Senegal, over the past three decades, the urbanization rate has risen from 34% in 1976 to 39% in 1988 and from 41% in 2002 to 45.2% in 2013 (ANSD, 2014). According to the same source, the Dakar region had a rate of 96.4% in 2013. This translates into galloping urbanization on a national scale, but which remains much more advanced in the region. This urban demographic growth, determined by migratory movements and natural demographic growth, is accompanied by housing, food and employment needs that are real problems in cities. These difficult situations reinforce the process of impoverishment of large sections of the population. Dakar accounts for over 50% of the urban poor (Gaye and Niang, 2010). Yet the city is often unable to meet the needs of its population, resulting in increased urban poverty and food insecurity. In Dakar, the Niayes wetlands are generally used for market gardening, thanks to their favorable hydro-soil and climatic conditions. They contribute significantly to community livelihoods and provide services such as groundwater recharge, water filtering and breeding grounds for economically important aquatic species (UICN, 2009). Despite these multiple functions and services to human societies, wetlands are among the ecosystems most threatened on a global scale by anthropogenic activities (Lefeuvre et al., 2003; OZHM, 2012; Rouissi et al., 2016). In addition, the functions and services they provide to society, combined with their fragility, have made them a focus of international concern. The adoption of the Ramsar Convention in 1971 demonstrates the international community's interest in the conservation and wise use of wetlands. Valuable for market gardening, they ensure a constant supply of water and fertile soil. However, the development of market gardening is accompanied by the use of large quantities of pesticides and the need to extend cultivated land to better meet the city's growing demand for fresh vegetables. An assessment of pesticide flows in the Dakar agrosystem revealed a total pesticide flow of 60kg/ha/year (Guéye, 2010).

It is therefore necessary to reconcile the ecological function and economic value of these natural environments in order to promote agricultural practices that are more respectful of the environment.

The aim of this study was to gain a better understanding of the spatial evolution and management of market gardening in this wetland, as well as the relationship between market gardening and ecosystem services. The management of urban market gardening, particularly which of urban wetlands, is a topical issue given their importance in a context of galloping urbanization.

MATERIALS AND METHODS

The situation in the Niaye de Pikine

The Niaye de Pikine belongs administratively to the department of Pikine. It is essentially located in the commune of Pikine Ouest (figure 1). It includes the Niayes area of Dakar, which stretches over a length of 30 km and a width varying from 1 to 8 km inland (PASDUNE, 2004), with a surface area of 4,800 ha. The Niayes region is 260 km long and between 5 and 35 km wide (Bâ, 2007), covering the Atlantic fringe of the Senegalese coast from Dakar to Saint-Louis. The Niaye is a wetland ecosystem comprising a network of fragmented basins, formed by ancient valleys and inter-dunal depressions where the water table is exposed. The surface water contained in the depressions, which is the source of the ponds, is mainly derived from the underground flow of infiltrated water (Peeters, 1998).

Geomorphologically speaking, the Niayes are interdunal depressions in which the Quaternary sand water table outcrops or subcrops (Ndao, 2012; Dasylva and Cosandey, 2010; Diop, 2006). In the Niaye de Pikine, altitudes vary widely (Figure 2). Its many assets make it an atypical landscape in the Sahelian region (Dasylva and Cosandey, 2010). The water table extends all along the coast from Thiaroye to Saint-Louis (Chaoui, 1996). Originally, the vegetation of the Niayes zone took the form of islands of greenery whose characteristic area Niayes zone (Ndiaye, 1998). Annual rainfall corresponds to more humid regions such as the sub-Guinean zone (Ndong, 1990). The oil palm (Elaeis guineensis), which thrives in southern Senegal, was undoubtedly the characteristic plant of the Niayes. Vegetation was distributed in basins, red dunes, semi-fixed yellow dunes and on coastal white dunes (Figure 3). The Niayes zone is home to a wide variety of plant species. Nearly 419 plant species, or 20% of Senegal's flora, and 13 of the 31 species considered endemic to Senegal are found in the in the Grande Niaye de Dakar is estimated at around 400 mm per year, and the average temperature varies between 28°C and 36°C (Diop and Sagna, 2011).

Selection of study data

The data used for the study of land use dynamics are aerial photos from 1966, 1978, the 2004 orthophotorectified image and the 2022 satellite image (Digital Globe Over view 2). Their characteristics are listed in Table 1. These dates were chosen in order to understand the state of the Niayes before and after the great drought of the 1970s. The year 1966 coincides with the period of de-cluttering of the City of Dakar and the start of its peri-urbanization (Vernière, 1977). The 1978 image illustrates the period of the great drought that began in 1970 (Sène and Ozer, 2002). The year 2004 meanwhile, is marked by a gradual return to better rainfall (Decroix et al., 2015; Bodian, 2014). Finally, the year 2022 provides a representation of the recent situation in the study area.

A Shuttle Radar Terrain Model (SRTM) with a resolution of 30 m extracted from the UGSS database was processed to produce a digital elevation model (DEM). The GIS layer of the morphopedology of Senegal, accompanied by a legend (Source: USAID/ RSI Project No 685-0233, Mapping and remote sensing of natural resources for the National L and Use Plan) was used to identify soil types.

Cartographic processing

Data acquisition is followed by data processing. The images selected for this study were georeferenced and wedged, essential steps for diachronic analysis. These images were geometrically rectified and projected in the UTM/WGS 84/ZONE 28 North map projection system. The coordinates of the landmarks identified on the 2022 images were collected in the field using a GPS (Garmin model 62St). Georeferencing is the transformation of an image according to a reference cartographic system. It enables the images used to be superimposed so that equivalent geographical points coincide (EUROSTAT, 2001). Radiometric calibration has enabled digital counts to be converted to reflectance values (physical values), using the formula proposed by Chander et al. (2009). The image histogram was enhanced to extend intensity levels or grey tones from 0 to 255 values.

The resampling method is nearest neighbor, and the geometric correction was performed using a second-order polynomial transformation (Tendeng et al., 2016; Thieler et al, 1994; Shoshany et al., 1992; Durand, 1998). This involves matching points on the images with landmarks on the topographic maps. Validity was checked by estimating the standard error, RMSE (Root Mean Square Error). As RMSE is only an indicator, the validation of geometric corrections was completed by a visual check carried out by superimposing images. The threshold for spatial accuracy was an error of less than one pixel. They were then enhanced by dynamic spread and false color compositions (4-3-2) were created for better interpretation of image themes. The choice of channels was based on the near-infrared, where vegetation reflects best, and the two visible channels, red (channel 3) and green (channel 2).

ENVI 5.3 software was used to rectify with a second-degree polynomial, and 24 registration points per image were used. The rectified image 2022 was used as a reference for frame-by-frame registration of previous images. Then, to validate the geometric corrections, multi-date images were superimposed on the screen to check the superimposition of remarkable features and infrastructures present on or near the site (roads, vegetation, buildings, etc.). In the event of poor results, the image is rotated, scaled and translated to obtain a satisfactory superposition of the shots, so that they can be assembled and the various strata extracted. After georeferencing, we proceeded vectorization into done. This involves transforming raster data into vector data by creating polygons. Vectorization of the images by visual interpretation enabled to classify polygons with the same attribute into layers, with each layer corresponding to a land-use class. This method is often preferred for local diagnostics, involving the extraction of detailed information over small areas. For the production of large-scale land-use information, this method has many limitations: processing times, heterogeneity of interpretation, ten-year updating capacity (for aerial sources), sources of error that are difficult to estimate. These limitations make it unsuitable for monitoring purposes (Le Berre et al., 2005). Despite these limitations, photo-interpretation of satellite or aerial images remains a commonly used technique on a local or even regional scale (Thomson et al., 2007; EAA, 2007). The high resolution of satellite images (0.5 m for the years 2004 and 2022) has enabled good separation of the different land-use strata. The different strata can be identified by their reflectance values. In aerial photos (Figure 4), bare surfaces can be recognized by their white color. Water and flooded surfaces are respectively black and dark grey. Vegetation is light grey. Built-up areas can be identified by their dark gray and white hues, with easily identifiable alleyways.

The Over view 2 satellite image from Digital Globe 2022, 50 cm resolution (Figure 5), made it easier to distinguish the different strata on the basis of their spectral signatures. In addition, based on the interpretation of aerial photos, fieldwork (transects of the terroir, site visits, discussions with key informants such as notables and resource persons active at the time of our study or having developed socio-economic activities in the maraichage site in the past, for example) and the analysis of existing documents (morphopedological maps, vegetation maps), it was possible to define landscape units and study their evolution according to different dates.

However, the visual interpretation of the medium-scale aerial photographs did not allow the digitalization of the different types of land cover as was done on the satellite images. It also enabled to distinguish six (06) classes on the aerial photographs and eight (08) classes on the satellite images. All these classes were used to draw up the land cover facies map. The land cover classes were first described (Table 2).

The areas of each land-use class for all years were estimated from the attribute table in ArcGis software.

Validation of the mapping results was based on field observations, old topographic maps, previous studies (Diop, 2018) showing certain features of the previous landscape and informal semi-structured interviews carried out with market gardeners, and anyone else carrying out an activity in the area. On the other hand, the heterogeneity of the landscape and the differences in the sensors from which the images are derived can sometimes skew analyses of land-use dynamics. Multi-date comparisons can prove difficult if the detectable elements differ from one sensor to another. They can only have a major influence on land cover trends if their proportion is considerable. In the case of this research, these differences are rendered marginal by taking into account the results obtained from exchanges with resource persons who have developed an activity on the site, in this case market gardeners and reed harvesters for matting. The development of a Digital Elevation Model (DEM) enabled us to characterize the topography of the study area and to perceive variations in relief.

Statistical analysis

The land use class areas obtained were analyzed by calculating the Land Use Change Rate (Tc) according to the formula in (Toyi et al., 2013): T = A2-A1/ A1*100 where A2 and A1 represent the percentage proportion of the area of a land-use class in the most recent year and the oldest year respectively. Positive values of T mean an increase in the area of the land-use class, and negative values of T a loss or regression of area. A value close to zero indicates relative stability of the land-use class.

Survey

A survey was carried out using a questionnaire to gather information on the use of phytosanitary products (chemical fertilizers, pesticides and other products) in market gardening. The survey targets were the site's farmers, particularly the market gardeners. Over the entire site, eighty individuals were surveyed. To complete the qualitative data collection, an interview guide was applied to a group of people: the head of the wetlands division, the director of horticulture and the technical agents of the horticulture department.

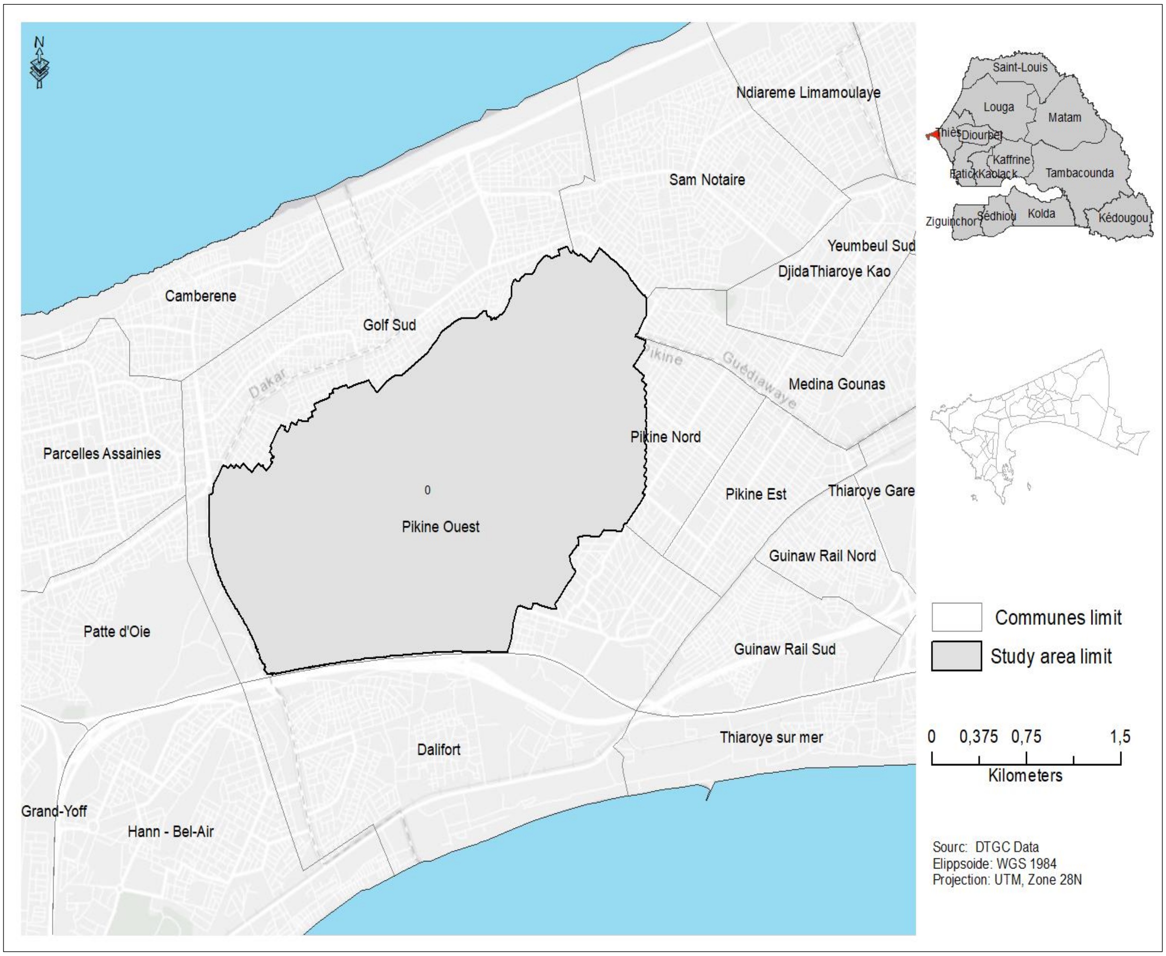

Figure1: Presentation map of the study area.

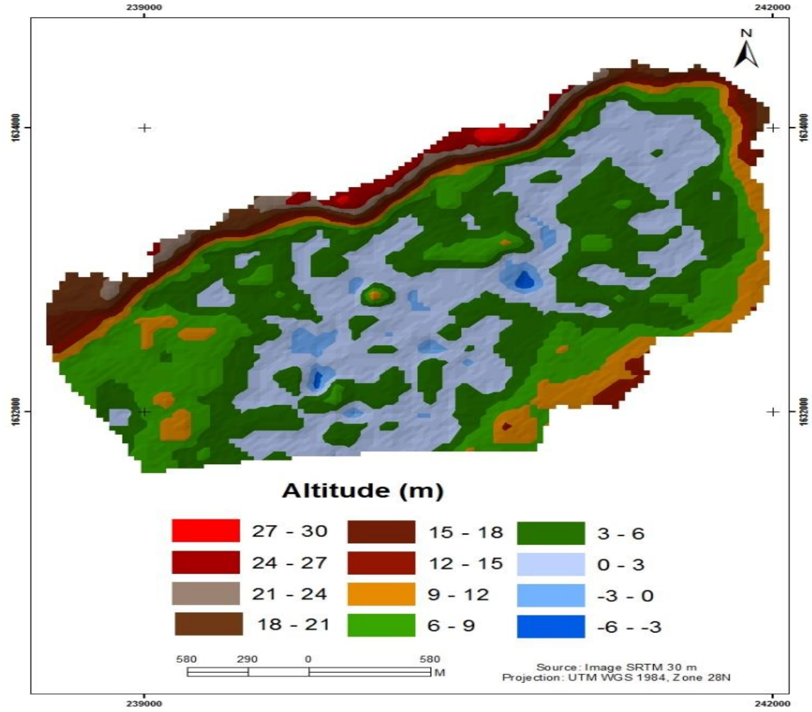

Figure 2: Digital terrain model of the study area.

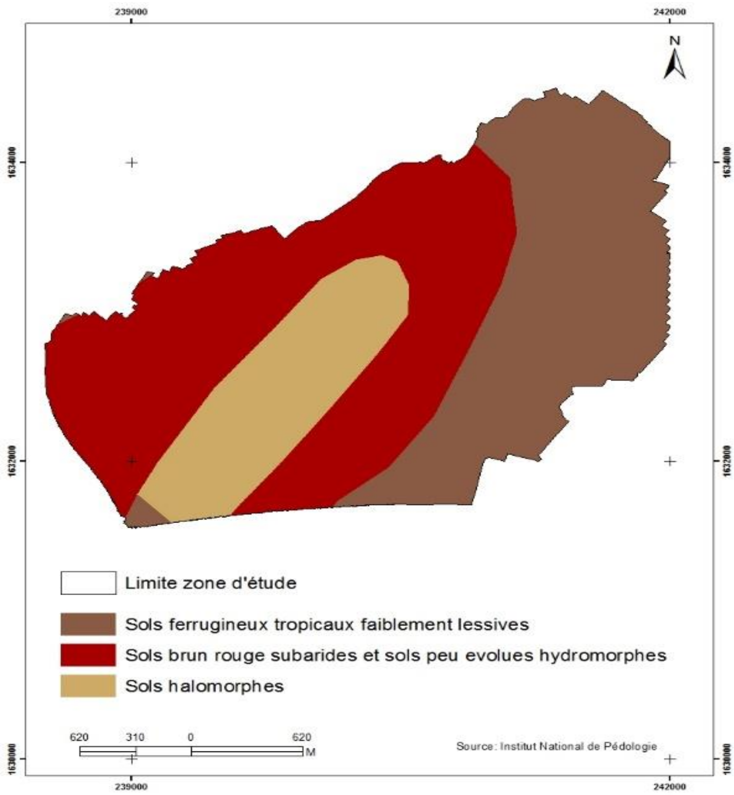

Figure 3: Soil types in the study area.

Table 1: Characteristics of the spatial data used for mapping.

Data	Years	Spatial scale or resolution	Projection used	Sources
Aerial photos	1966 & 1978	1/60000	UTM WGS 1984 Zone 28N	Geographic and Cartographic Works Department (DTGC)
Orthophotoctified	2004	Panchromatic 0,07m	UTM WGS 1984 Zone 28N	Ecological Monitoring Center (EMC)
Satellite image (Over view 2 from Digital Globe)	2022	Panchromatic 0,5m	UTM WGS 1984 Zone 28N	Municipal Development Agency (MDA)

Figure 4: Aerial photograph of the Niaye area of Pikine in 1966, at 1/60000 scale.

Figure 5: Digital Globe 2022 Over view 2 satellite image, 50 cm resolution.

Table 2: Occupancy classes and their description.

Land use classes	Description
Habitat	Constructions: buildings, structures, housing
Market gardening	Marker gardening farming
Dune vegetation	Plant formations on land and on dune slopes
Bare soil	Areas with little or no vegetation cover at the time the images or photos were taken.
Aquatic vegetation	Plant formations in ponds or flooded areas
Floriculture	Ornamental plant crops
Water	Stretches of water, ponds

RESULTS

Land use maps of the study area

On the Digital Globe 2022 Over view 2 satellite image, 50 cm resolution, vegetation cover in the color composition can be identified by reflectance values translated into green shading. Dark green represents dune vegetation and anthropized vegetation. Aquatic vegetation is characterized by the green gradient. Built-up areas are characterized by a light grey. Flooded surfaces are "dark grey". Bare ground can be recognized by its color, which varies between white and pink. Water appears in black.

Mapping of the dynamics of building, market gardening and other land-use units in the study area was analyzed using the 1966, 1978, 2004 and 2022 land-use maps. This mapping helped obtain

statistics for the various classes selected in the study area, and to analyze their spatio-temporal variations for the different years considered (Figures 6 and 7).

Figure 8 shows the dynamics of land use change over the study period. An analysis of mapping statistics from 1966 to 2022 shows, on the one hand, a progressive dynamic of buildings and aquatic vegetation and, on the other, a regressive dynamic of water bodies, bare soil and dune vegetation.

Market gardening, on the other hand, shows a slow and steady evolution, with the exception of 1978, when it dropped to 0.79%. However, its rate seems to be increasing significantly, reaching 12.54% in 2010, an increase of 105.83%.

The area occupied by buildings increased by 104 ha between 1966 and 2022, to the detriment of upland vegetation (Table 3).

This situation can be explained by the rapid urbanization of the Dakar region, which has led to the creation of new neighborhoods (Golf, Sahm Notaire, SOPRIM city) as well as the expansion of existing neighborhoods (Cambérène, regular Pikine). Numerous infrastructures have already been built in Niaye area of Pikine, including the National Society of Telecommunications. In addition, as part of the Technopole project, the golf club, Fayçal, city Lobat Fall city and other structures were built (Photo 1). These various structures have seriously altered the Niaye ecosystem, which plays an important ecological role in addition to its status as a RAMSAR site.

Another factor is the development of road infrastructures. The construction of the Axe 4 road (Figure 9) has contributed to the fragmentation of the Niaye area of Pikine ecosystem.

Today, the eastern portion of the habitat, isolated and fragile, is subject to very strong land pressure. It is in this area that the national arena (Figure 10) is being built, a project that has given rise to much debate. As a result, several market gardeners and residents have been evicted. Indeed, the absence of land titles or occupancy permits places market gardeners and other site occupants such as horticulturalists and reed harvesters in a very precarious situation. So, if need be, the State or property developers do not hesitate to evict them. Confrontations often occur when the occupants resist. For a long time, construction in the area was concentrated around the large depression. Today, with population growth in the Dakar region leading to a scarcity of living space, the wetland is the object of much covetousness on the part of crooked developers, often with the complicity of state authorities. The wetland's surface area is being increasingly depleted by built-up areas and other infrastructures, particularly industrial plants. This situation represents a real risk for the future of this wetland. Backfilling operations (Figure 11) carried out upstream of buildings disrupt the surface water drainage system and can, in the long term, dry out poorly-fed pools.

The surface area of water bodies underwent a gradual decline of 115.31 ha between 1966 and 2004, before rising again by 48.24 ha between 2004 and 2022. However, it remains lower than in 1966. This reduction in surface area can be explained by the drop in precipitation recorded during the rainfall deficit period (early 1970s). The return of rainfall noted since the 2000s, and in particular the large quantities recorded in 2005, 2009, 2012, 2021 and 2022, have undoubtedly led to an increase in the surface area of the water bodies. Added to this is the drainage of rainwater from several districts of Pikine towards this natural outlet. This situation leads to flooding, often forcing growers to abandon their gardens temporarily or permanently (Figure 11).

Vegetable-growing areas show a progressive trend, albeit discontinuous. Market gardening is generally carried out in the wetlands near bodies of water. Between 1966 and 1978, market garden area increased by 4.43 ha. The extension of market gardening areas can be linked, on the one hand, to the rural exodus observed during this period and, on the other, to the availability of fertile soils and the permanent presence of water in the area. However, beyond the flooding noted in recent years in the area, the spatial evolution of market gardening remains confronted with two major obstacles: the salinization of the soil and the extension of the built-up area. Indeed, because of land speculation, market gardeners confirm that they face the constant risk of land grabbing by private developers or individuals claiming to own land, as demonstrated by the recent eviction of nearly twenty market gardeners and horticulturists for the benefit of a property developer. According to them, the current SONATEL and SENUM S.A site used to be home to market gardens that had to be cleared. Despite these difficulties, market garden acreage is now on the increase, no doubt due to the importance of consumer markets. Even so, market gardening in the Niaye area of Pikine is a major environmental challenge. In fact, despite its multifunctional dimension, market gardening raises a number of environmental issues that need to be urgently addressed. Indeed, the need to expand market-gardening areas and increase yields to meet growing demand for vegetables is driving market-gardeners to practices that are harmful to the environment. In the context of this work, we are mainly interested in practices that degrade natural resources, including the use of chemical fertilizers and phytosanitary products. The surveys carried out during this study revealed the use of pesticides to control insects and weeds, which are a real threat to market garden production. Pesticides include fungicides, insecticides and herbicides, depending on the organism targeted by the active substance. However, when used improperly, these pesticides can be the source of pollution that can alter the quality of the environment.

Survey results also showed that virtually all vegetable growers use pesticides to control whiteflies, aphids, caterpillars, etc. The most commonly used products are dursban, dimethoate, dicofol, cypermetrine, mocap, furadan, lanate and maneb. Durban, dimethoate, dicofol, cypermetrin, mocap, furadan, lanate and maneb are the most widely used products. However, there is a problem of non-compliance with the standards for the use of these products, compounded by the absence of a suitable control mechanism. This could encourage the use of excessive quantities of pesticides, which could lead to public health problems (Figure 12).

According to the market gardeners surveyed, 89% have used pesticides, which can be applied several times, in several stages before transplanting, at the vegetative stage and when the plant is under attack. Pesticide dosage is one of the main difficulties faced by growers. The volumes used are generally not quantified, and several pesticides may be mixed without taking into account either the doses usually indicated on the packaging, or compatibility; the result is often a substance with unknown properties. The areas covered by upland vegetation and bare soil have declined by 160.67 ha and 27.7 ha respectively between 1966 and 2022. In particular, the expansion of the built-up area is the main cause.

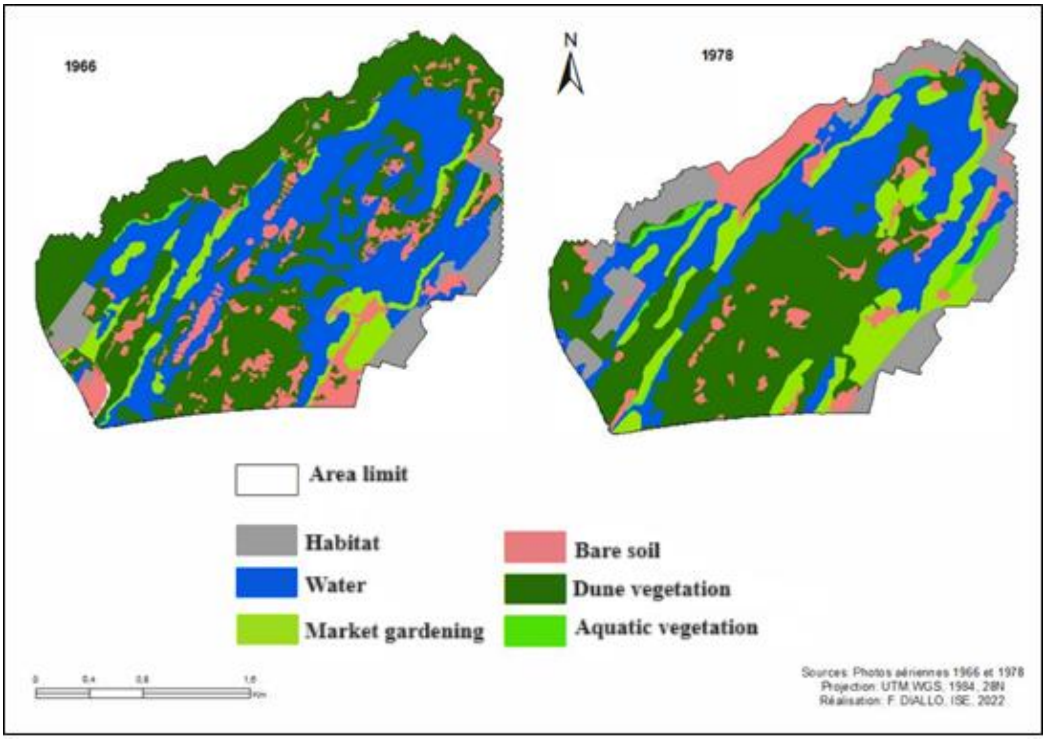

Figure 6: Land use dynamics in the Niaye area of Pikine from 1966 to 1978.

Table 3: Land use class statistics for the Niaye area of Pikine between 1966 and 2022.

Classes	Years Surface area in Hectares								
	1966	**%**	**1978**	**%**	**2004**	**%**	**2022**	**%**	**evolution (%)**
Habitat	34,71	5,37	84,27	13,04	99,65	15,42	138,71	21,47	299,62
Water	220,09	34,07	165,41	25,6	104,78	16,22	153,02	23,69	-30,47
Floriculture					4,45	0,69	2,98	0,46	
Market gardening	44,95	6,96	49,38	7,64	44,4	6,87	47,23	7,31	5,07
Bare soil	73,67	11,4	105,14	16,28	70,43	10,9	45,97	7,12	-37,6
Dune vegetation	264,13	40,88	228,99	35,44	231,14	35,78	103,46	16,01	-60,83
Aquatic vegetation	8,51	1,32	12,87	2	91,21	14,12	154,69	23,94	1717,7

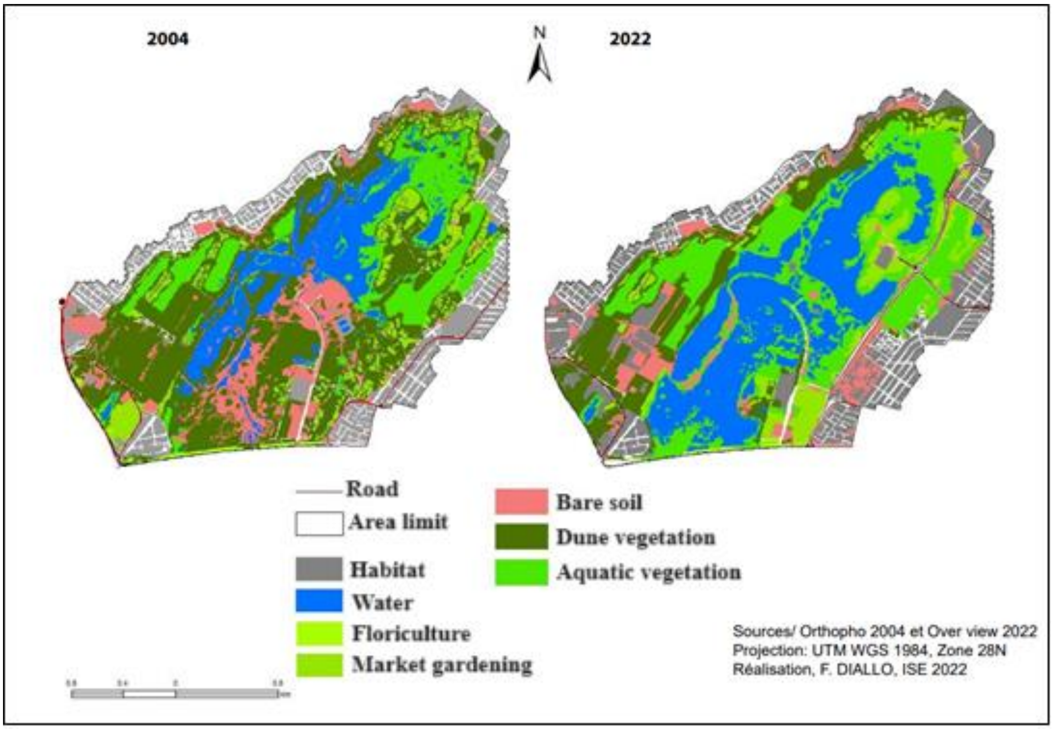

Figure 7: Land use dynamics in the Niaye area of Pikine from 2004 to 2022.

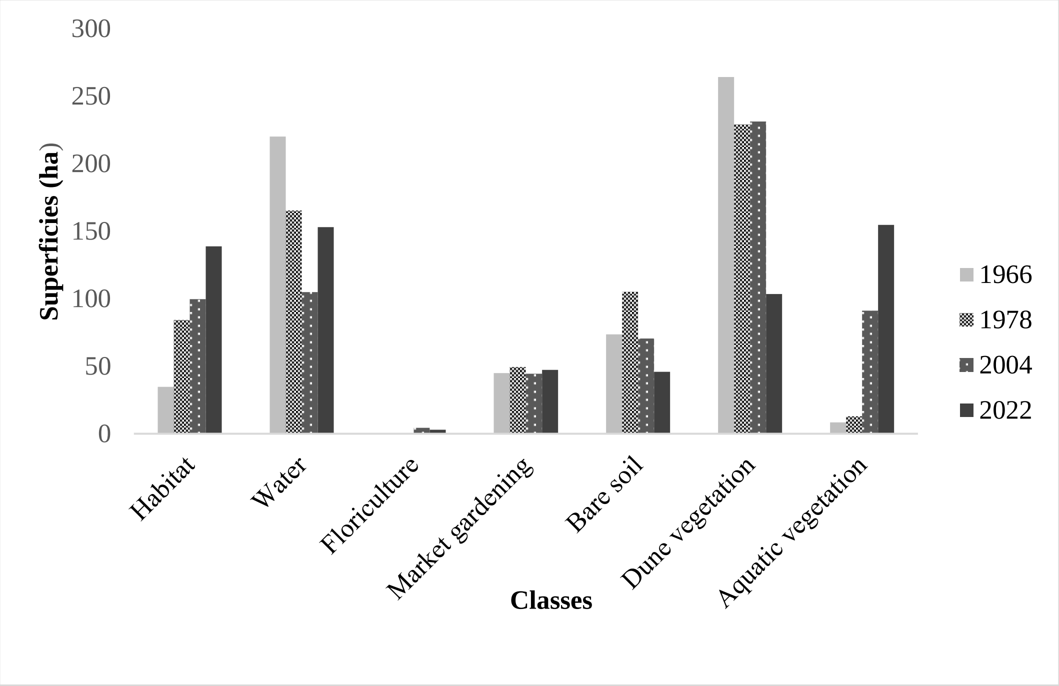

Figure 8: Land use dynamics in the Niaye area of Pikine from 2004 to 2022.

Figure 9: Urbanization in the Niaye area of Pikine: (A) Fayçal citie , (B) headquarters of SENUM SA.

Figure 10: Road network built in the Niaye area of Pikine.

Figure 11: Backfilling carried out in 2015 in the Niaye area of Pikine for the building of the National Wrestling Arena.

Figure 12: Types of pesticide (C) and foncicide (D) used by market gardeners in Niaye area of Pikine.

Figure 13: Proliferation of Typha australis (A) and Typha domingensis (B) in the Niaye area of Pikine.

DISCUSSION

Land use dynamics

Analysis of the spatio-temporal dynamics of agricultural and built-up areas in the Niaye area of Pikine and its riparian terroirs shows a progressive amplitude of built-up areas of almost 300% over 57 years. These results are in line with those of Tih (2014) in the Dakar technopole area, as well as those of Diop (2018), who show a continuous progression of built-up areas to the benefit of dune vegetation and bare soil. Similarly, Ndao (2012), in a study carried out in the same area, found an increase in built-up areas, with an evolution rate of 142.78% between (1966-1978) and 18.25% between (1978-2004). In his view, this trend can be explained by the unbridled suburbanization of Dakar from 1968 onwards.

The low rate of built-up area, 5.37% in 1966, reflects the low level of urbanization in the Niaye area of Pikine and therefore the low level of anthropogenic influence. There were 300,000 inhabitants in the Dakar region at the time (ANSD, 2010). As the population has grown, so has the built-up area. According to an ANSD report published in 2007, the significant increase in the population of the

Dakar region is mainly due to the rural exodus, which was very marked in the 1970s, following the major droughts that affected the whole of West Africa. What's more, the Dakar region and Dakar department in particular are home to the country's major administrative and political centers, as well as its largest economic infrastructures. Market gardening, on the other hand, has evolved slowly. Between 1966 and 1978, it increased from 44.95 hectares to 49.39 hectares, for a growth rate of 9.85%. Between 1978 and 2004, however, the rate fell to -10.08%. The low rate of market gardening observed in 1966 could be explained by the fact that in 1966 the population of the Dakar region was still small, and vegetables did not play an important role in the dietary habits of the local population. Furthermore, the small area occupied by market gardening in 2004 could be the result of the landfill operations undertaken on the site since the 1980s (Diop, 2006; Ndiaye, 2010). Despite the influence of the drought, a satisfactory freshwater level persisted, enabling market gardening to take place (Ndao, 2012). The retreat of water bodies following landfill operations and the increased demand for arable land have also enabled market gardening to colonize new areas (Dia, 2003). Floriculture was present in 2004 alongside market gardening, albeit on a small scale with a surface area of 4.45 hectares. The decline in arable land in Pikine in favor of urban development is part of the sprawl of the Dakar conurbation. The work of Diop (2006) confirms this study in the Niaye area of Pikine. These results corroborate those of Diop et al. (2019) who showed that the demographic explosion and the multiplication of players in natural areas with agricultural vocation, have undergone strong mutations. Diop (2012) confirms that horticultural land in the Dakar region declined by 6% between 1988 and 1994. In 2008, 655 hectares of farmland had been converted to residential areas. Also, Diop (2018), says that in the Niaye area of Pikine, rapid urban dynamics pose a threat to the future of agriculture. Assessing income from market gardening in the Niaye area of Pikine production zone was not an easy task. Indeed, market gardeners are often reluctant to answer questions about their income. As a result, quantities sold and their prices are often underestimated, or production costs are overestimated (Bognini, 2006). This may be deliberate, but can also be explained by the fact that most market gardeners are illiterate and do not keep regular accounts. Nevertheless, all the market gardeners interviewed confirmed the increase in their income. According to the market gardeners interviewed, income from market gardening was estimated at around 100,000 F cfa per harvest. In contrast, these days a market gardener can earn up to a million (1,000,000Fcfa). Furthermore, the use of certain products or substances to improve yields and protect plants, such as pesticides and chemical fertilizers can be the source of a public health problem. The uncontrolled use of these toxic substances affects both the health of market gardeners and consumers, and the quality of the environment's natural resources. Ngom et al. (2013) confirmed the presence of pesticide residues used to spray plants in some vegetable samples taken from a market garden plot, just after picking. Given the ever-increasing importance of fruit and vegetables in diets, and the recommendation to consume a minimum quantity of them, the overuse of pesticides in market gardening could pose a real danger to human health. In addition to the danger posed by pesticides to humans, they also increase the risk of groundwater contamination. The work of Gaye and Niang (2010) revealed the presence of many parasites in tomato and lettuce samples irrigated with raw wastewater. Similarly, the use of raw sewage is commonplace in the Niaye area of Pikine. This form of wastewater recycling offers many advantages for the development of market gardening. However, these contain pathogenic microorganisms that can survive in water, soil and on vegetables. The presence of these various microorganisms increases health risks for both producers and consumers. Untreated or partially treated water is an alternative source of water for crop irrigation. Highly nutrient-rich, it eliminates the need for chemical fertilizers. The main use of this water in Dakar is in Pikine, with around 32% of the total irrigated area (Gaye and Niang, 2010).

Changes in the surface area of water bodies vary over time. It decreased by 24.84% between 1966 and 1978, and by 36.65% between 1978 and 2004. They increased between 2004 and 2022, with a surface area of 153.02 hectares, representing a growth rate of 46.03%. Like the cultivated areas, the variation in the extent of water bodies could also be explained by the period of time when the processed satellite images were taken. As a reminder, the processed images were taken between February and March. Similarly, the advancing urban front also blocks waterways, reducing surfaces for rainwater infiltration (Ndiaye, 2012). The Niaye River collects and stores runoff. Water stagnation appears to be a recent phenomenon (Ndiaye, 2012) and is due to Dakar's urbanization problems and the return of more abundant rainfall. Aquatic vegetation grew slowly between 1966 and 1978, increasing by 4.36 hectares. However, it increased significantly between 1978 and 2004, adding 78.34 hectares, an increase of 608.7%. The expansion of aquatic species, notably the massive development of freshwater macrophytes *Typha domingensis* and *Phragmites australis* (figure 13) may be due to the drop in salinity resulting from the significant recharge of these water bodies by rainfall (Diop, 2006; Diouf, 2011).

These species are a nuisance in some of the wetlands they occupy and create ecosystem dysfunction, particularly in agricultural wetlands such as the "Niayes", where water levels fluctuate throughout the year. (Kane and Akpo. 2015). In addition, *Phragmites australis* is used for phytoremediation of various types of wastewater, soil and sediment (Rezania et al. 2019; Nocetti et al., 2020). As for *Typha domingensis,* it is well adapted to polluted environments and has the power to eliminate and accumulate heavy metals in its tissues (Mufarrege et al., 2020; Hadad et al., 2020). On the other hand, dune vegetation appears to be declining between 1966 (year of highest cover rate: 33.92%) and 1978 (lowest rate). By 2004, vegetation cover had increased to 7.59%, before dropping again to 6.4% by 2022. The drop in surface area recorded in 2022 can be explained by the increase in the volume of water, the permanent presence of which causes asphyxiation in plants unable to withstand permanent flooding. The drop in dune vegetation cover noted in 1966 could also be attributed to long, severe periods of drought, as well as to strong human pressure on plant resources.

The increase in bare soil in 1978 could be attributed to the long droughts of the 1970. The increase in bare soil between 2004 and 2022 can be attributed to the growth of the built-up area. Upland vegetation declined throughout the study period. It fell from 264.13 hectares in 1966 to 103.46 hectares in 2022, a decline of -60.82%. The decline in vegetation cover on the plateaux (dunes) could also be attributed to the long and severe periods of drought, but above all to the strong anthropic pressure exerted on plant resources for urbanization purposes. Indeed, the economic development of several sectors in the country, notably tourism, equipment and transport, has led to a significant demand for urbanization (Catin et al., 2008). Depending on their intensity, these anthropogenic pressures lead to quantitative changes (degradation or reduction in the surface area of ecosystems) and/or qualitative changes, resulting in dysfunctions and a loss of the bioecological values of natural environments (Muller et al., 2011; Rhazi et al., 2012). The woody species of the Ndiaye de Pikine were mainly concentrated at the foot of the slopes of the fixed dunes, with mainly Guinean species such as *Elaeis guineensis*. Cultivated woody plants are mainly found in cultivation plots and sporadically outside cultivated perimeters Tih Chuienui Nadia (2014). The heterogeneity of woody species is the result of anthropogenic activities in the site. Indeed, the expansion of agricultural land and urban development are taking place at the expense of natural formations (Bouko et al. 2007). In general terms, living communities adapt to the various constraints and disturbances of the surrounding environment (Serpanitié and Duvineau, 1991); thus, the fragmentation of ecological systems in cultivated areas conditions the sustainability of natural biocenoses (Bangirinama et al. 2011).

Conclusion

This study focused on the spatio-temporal dynamics of agricultural and built-up areas in the Niaye area of Pikine wetland, with the aim of analyzing the spatial evolution of agricultural and built-up areas in order to identify related environmental problems. It highlights the anthropization of the Niaye area of Pikine, marked by galloping urbanization, leading to the degradation of the physical environment and the reduction of agricultural land. The future of market gardening, which provides a livelihood for a large number of players, is uncertain. The megacephaly from which Dakar suffers is the main threat to the Niaye area of Pikine. For a long time, this wetland was sparsely occupied by buildings, but is now surrounded by a large urban area. It's a high-stakes site for economic players, private developers and the State, who see it as a land reserve that can be built on if need be. What's more, wetlands such as the Niaye area of Pikine are no longer a natural obstacle to modern construction techniques. If nothing is done in the next few years, the water bodies could be drained to accommodate urban facilities, including housing and other human activities, and the market gardening industry, which is highly dependent on them, could disappear. Construction is not the only threat to the Niaye; the use of certain environmentally harmful products in market gardening and other methods of resource exploitation are also threats. Serving as a catchment area for runoff from a large part of the Dakar region. The Niaye area of Pikine should benefit from a comprehensive urban development plan, including a well-adapted drainage system, because of its susceptibility to flooding, which has become a major concern for the population with the return of more abundant rainfall. This study can serve as a basis for state decision-makers in defining priority areas and restoring ecologically important humic zones.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

FBD and HS participated in the design and planning of the study. FBD collected and entered field data. FBD and HS carried out the statistical analyses, interpreted and drafted the first version of the manuscript. HS and CSF participated in the critical revision of the manuscript and agreed on the final version to be published. All authors authorize publication of the final version.

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