frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 05 December 2023
DOI 10.3389/fenvs.2023.1124637

OPEN ACCESS

EDITED BY
Martin Siegert,
University of Exeter, United Kingdom

REVIEWED BY
Yuheng Li,
Chinese Academy of Sciences (CAS), China
Adrian Ursu,
Alexandru Ioan Cuza University, Romania

*CORRESPONDENCE
Guoming Du,
duguoming@neau.edu.cn

RECEIVED 15 December 2022
ACCEPTED 10 November 2023
PUBLISHED 05 December 2023

CITATION
Faye B, Du G, Li Q, Sané T, Mbaye E and Zhang R (2023), Understanding the characteristics of agricultural land transition in Thiès region, Senegal: an integrated analysis combining remote sensing and survey data.
Front. Environ. Sci. 11:1124637.
doi: 10.3389/fenvs.2023.1124637

Understanding the characteristics of agricultural land transition in Thiès region, Senegal: an integrated analysis combining remote sensing and survey data

Bonoua Faye[1], Guoming Du[1,2]*, QuangFeng Li[1], Tidiane Sané[3], Edmée Mbaye[4] and Rui Zhang[2]

[1]School of Public Administration and Law, Northeast Agricultural University, Harbin, China, [2]School of Economics and Management, Northeast Agricultural University, Harbin, China, [3]Department of Geography, UFR Sciences and Technologies, Assane SECK University, Ziguinchor, Senegal, [4]Department of Geography, Cheikh Anta Diop University, Dakar, Senegal

Adopting an integrated analysis is a prominent tool for a coherent understanding of the characteristics of agricultural land transition in developing countries. Hence, using an integrated analysis combining remote sensing and survey data, this investigation aimed to understand the spatial-temporal distribution and intensity of agricultural land transition in Senegal through a case study in the Thiès region. Through ArcGIS and ENVI software, we interpreted the land use types from 2000 to 2020 and the transfer matrix method used to characterize the agricultural land transition. Then, the Pearson correlation coefficient is used to determine the intercorrelation between natural and socio-economic driving factors of agricultural land use. The main results show that agricultural land transition was about −588.66 km^2. Grassland was the most crucial land morphology to participate in this transition. Regarding spatial distribution, the highest net transition of agricultural land was recorded in Mont-Rolland (33.22%) and the lowest in Sandiara commune (−41.73%). The temporal distribution is represented in Koul, with −0.35%, and Mont-Rolland commune, with 24.84%. The intensity of agricultural land transition was high in Malicounda commune, at 11.34%. The social survey also shows a strong relationship between wind erosion and land salinity (0.971) as potential driving factors that may induce agricultural land transition. Based on an integrated method, the contribution of this study enhances the theoretical approach and methodology for assessing the mean potential driving factors in developing countries such as Senegal. Consequently, agricultural land transition in Thiès region was complex and must be implemented with complex and comprehensible policy solutions.

KEYWORDS

Thiès-Senegal, agricultural land transition, integrated analysis, spatiotemporal distribution, social survey

Introduction

Agricultural land transition has become an important component of the environmental risks that require immediate and long-term solutions. Many researchers have studied the changes in agricultural land use due to socio-economic development (Shi Ge, 2018; Zhou et al., 2021). In early 1970, a few scholars highlighted that agricultural land is fundamental to human survival and economic development (Bell and Borgstrom, 1966). Hence, it is implied that agricultural land use and socio-economic development have gone hand in hand for a long time. What's more, many driving factors increasingly threaten agricultural land, such as the need for land for housing (Faye, Du and Zhang, 2022), urbanization (Lyu et al., 2021), socio-economic development (Niu Bo et al., 2021) and so on. Conversely, agricultural production and economic growth depend on land availability, which has a dual relationship. From then on, a comprehensible analysis of agricultural land transition is a prerequisite to optimal utilization (Amara et al., 2021).

For this reason, among various research trends, coordinating socio-economic development, which needs land and agricultural land area for production, has recently raised huge concerns worldwide. In other words, agricultural land decline or transition is central to scientific research papers addressing food security. So, governments and scientific researchers are increasingly interested in the potential factors influencing the agricultural land transition. As an ecosystem service value, agricultural land provides multiple and diverse contributions to socio-economic development. Or, ecosystem service value is indispensable when balancing the need for food production and ecological protection because it can clarify a region's environmental assets and values (Li et al., 2022).

However, the process of agricultural land transition is often non-linear and may revolve around two interrelated questions: the physical environment and socio-economic driving factors (Paul and Rashid, 2017; Ustaoglu and Williams, 2017; Faye and Du, 2021), and it is associated with other societal and biophysical system changes (Lambin and Meyfroidt, 2010). In that situation, the intensity of land use is directly related to how land is used, especially agricultural land (Sang et al., 2019). Relevant studies point out that increasing food demands are causing rapid changes in farming systems, often involving intensified land use (Kuchimanchi et al., 2021). Simultaneously, many developing countries have policies to transition from subsistence farming into market-oriented approaches in response to the increased demand for animal-source food (Kuchimanchi et al., 2021), and the need for crop production is increasing globally (Awoonor et al., 2021). As a result, both situations have the potential to stimulate new land use while also reshaping agricultural land morphology. This situation was observed in Ivory Coast, whose agricultural land extension caused the diminished forest land area (Kouassi et al., 2021). Therefore, this change in agricultural land use can critically impact environmental resources, biodiversity, and, eventually, human wellbeing. Along with the above issue, other studies suggest that converting grassland, wetlands, and forests to croplands may contribute to environmental degradation and diminished ecosystem sustainability (Joshi et al., 2019). So, the connection between ecological risk and agricultural land changes could hurt the agricultural land's fertility. In the statement, guaranteeing food security and conserving agricultural land size qualitatively while preserving the environment are global concerns.

In addition to these issues, population growth can threaten agricultural land morphology. By 2100, the world's population is projected to reach approximately 10.9 billion, with annual growth of less than 0.1% (Anthony Cilluffo, 2019). This estimate is comparable to our study area (Thiès region), which had approximately 1,788,864 inhabitants in 2013, with a projected 2,464,554 inhabitants by 2025, according to the National Agency for Statistics and Demography of Senegal (ANSD). Along with this projection, due to economic policies that may increase income, developing countries are expanding their economies and urbanizing their populations, which could endanger the environment (Pachiyappan et al., 2022) and threaten the availability of agricultural land. In this context, the process of agricultural land transition may be critical due to the need for a new land area for developing economic growth. For example, in Northeast China from 2000 to 2020, 81.6% of the land occupied by the expansion of rural settlements came from cultivated land (Wang et al., 2022). Therefore, socio-economic and population growth influence agricultural land availability, as is evident. In addition, we can see population migration from rural to urban areas in COVID-19, which may contribute to the emergence of additional suburban towns (Faye, Du and Zhang, 2022), threatening agricultural land in the peri-urban zone. So, compared with industrial countries, over the past century, agricultural land use in the United States has seen drastic shifts to support the increasing demand for food and commodities (Spangler Kaitlyn, 2020). Throughout this context, we assume that the unplanned expansion of built-up areas toward peri-urban cities has accelerated agricultural land transition, leading to farmland losses (Erasu Tufa Duguma, 2022). The rapid development of agriculture is inseparable from the strong support of finance (Yang et al., 2022). Or the lack of finance for agriculture may induce land abandonment. In this case, land abandonment has positive and negative consequences on the landscape's abiotic and biotic components (Subedi, Kristiansen and Cacho, 2022). Consequently, understanding the characteristics of agricultural land transition is becoming more complex. In other words, agricultural land management became a crucial challenge in Senegal.

Accordingly, urbanization is another major social, economic, and demographic trend with consequences for the structure and function of agricultural landscapes (Vanbergen Adam J, 2020). For this reason, implementing new agricultural land policies and economic development in coordination with natural and socio-cultural factors may go hand in hand. However, it should be clear that research on agricultural land use would help stakeholders make better agricultural resource decisions. Because of the importance of agricultural land, certain governments develop more cutting-edge research policies for managing agricultural land to achieve this goal. For instance, the governments of Russia (Chigvintsev Victor, 2020) and Australia (Naudiyal Pratibha, 2021) implemented a new approach to technical, economic, and agricultural development policies to ensure food security and protect agricultural land. In Senegal, the primary land use policies have not been significantly reformed since 1960 (Niang, 2017). However, the main question is how agricultural land transition can be accomplished in Senegal without significant land policy reform.

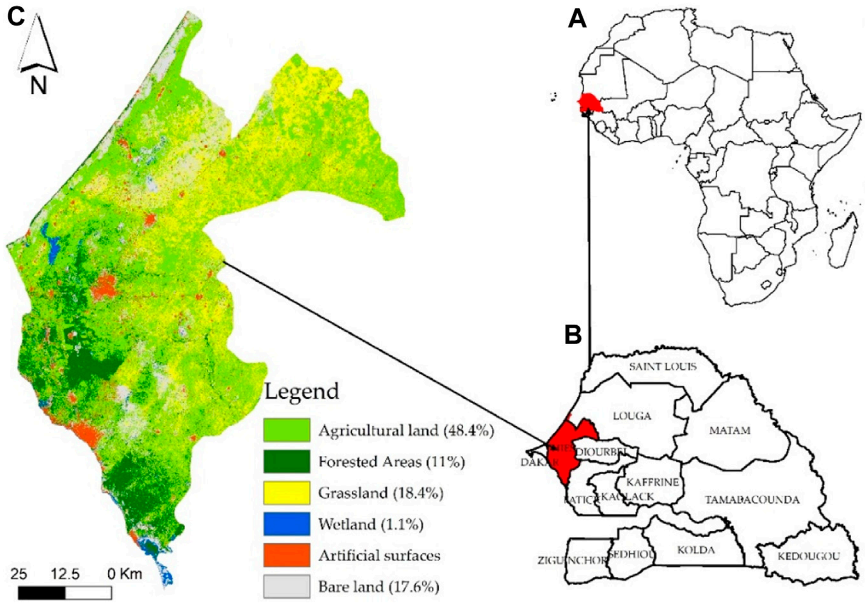

FIGURE 1
The localization of the study area, **(A)** African continent, **(B)** Senegal country, and **(C)** Thiès region.

What is the potential influence of public policy on agricultural land transition? Are agricultural land's initial and subsequent driving factors sufficient to comprehend without the farmer's perception of agricultural land transition? Which new research methods can be implemented to make Senegal's agricultural land transition process apprehensible? As a result, the research trend shows that GIS technology provides a flexible tool for spatial and statistical analyses coupled with modelling (Rozario et al., 2017). So, the combination of spatial statistics provided by remote sensing images and survey data may significantly impact the comprehensive understanding of the process of agricultural land transition in Senegal, in particular in the Thiès region. There is, however, a paucity of studies evaluating the characteristics of agricultural land transition with an integrated method. In that sense, this study is significant because it can contribute to and state farmers' perceptions about the causes of agricultural land transition while also highlighting policy shortcomings that may induce a rapid agricultural land transition. In another sense, this investigation was critical because we expected it to stimulate research on sustainable agricultural land management systems that can directly contribute to national food security policies and improve Senegal's land use information.

Following this ascertainment, this article provides a new approach and methodology for comprehensively understanding Senegal's agricultural land transition process. From then on, through an integrated analysis using remote sensing and social survey data, this investigation aims to understand the spatial-temporal transition of agricultural land in Senegal through a case study in the Thiès region from 2000 to 2020. Our specific objectives are: 1) to quantify agricultural land use transition; 2) to analyze the spatial and temporal distribution of agricultural land transition and its intensity; and 3), through the simple regression analysis model, to assess the farmer's perception regarding the influencing potentials and driving factors of agricultural land transition. So, the present study may provide significant insights into understanding the dynamic evolution of agricultural land in Senegal.

Overview of the study area

The spatial extent of Thiès region is between 10° 44′ 46″and 10° 52′ 46″north latitude and 78° 39′ 11″and 78° 44′ 13″west longitude. Thiès region was once an agricultural country where agriculture, especially groundnuts and vegetables, became essential to Senegal's economy. Regarding land area, it is one of the smallest regions in Senegal, at about 6669.6 km^2 or 3.35% of the total area of Senegal. As shown in Figure 1-b, it is bounded to the North by the Louga region, south by the Fatick region, west by the Atlantic Ocean and Dakar region (the capital of Senegal), and to the east by the Diourbel and Fatick regions. The Thiès region had 2,162,831 inhabitants in 2020, according to ANSD.

From the perspective of the agricultural situation, the main crop types are peanut, maize, millet, sorghum, and cowpea. According to the agricultural data collected in ANSD (accessed on 22 October 2022, at https://senegal.opendataforafrica.org/gallery?tag=DAPSA), the sown land area of these main crop types listed above represented about 266,668.24 hectors in 2020. In the same period, the agricultural production of these crops was around 25,3784.08 tons. From the point of view of spatial land use morphology, the remote sensing image analysis in 2020 shows that agricultural land use (48.4%) and grassland land (18.4%) represented the most significant land area dominant morphology, accounting for 66.8% of the total. Similarly, artificial surfaces represented 3.5% of the region's land area. Then, in this region, the topography is flat except for the

TABLE 1 Satellite images gathered for this research and their information.

Year	Acquisition date	Image Types	WRS Path/Row	Proportion of cloud%	Collected date
2000	11-November	Landsat7 ETM + C1	205/50	1	31 August 2022
	11-November	Landsat7 ETM + C1	205/49	7	31 August 2022
2005	17-September	Landsat7 ETM + C1	205/50	1	28 July 2022
	17-September	Landsat7 ETM + C1	205/49	5	28 July 2022
2010	25-October	Landsat 5 TM C1	205/50	0	28 July 2022
	25-October	Landsat 5 TM C1	205/49	6	28 July 2022
2015	24-Novomber	Landsat8 OLI	205/50	0.02	21 August 2022
	24-November	Landsat8 OLI	205/49	3.56	21 August 2022
2020	20-October	Landsat8 OLI	205/50	1.94	22 August 2022
	20-October	Landsat8 OLI	205/49	1.35	22 August 2022

"Plateau of Thiès," which culminates at 105 m of altitude. The temperatures are generally high, and the annual temperature cycle is complex. The maximum temperature is 33.2°. In addition, the interannual evolution of rainfall shows that the average rainfall was about 461.65 mm from 2000 to 2020, according to the data collected by the National Agency of Civil Aviation and Meteorology (ANACIM). The soil's characteristics were ferruginous tropical sandy soils that are slightly leached (Tappan et al., 2004).

Material and method

Data sources

Remote sensing data

The shapefile data corresponding to the limit of the administrative communes was collected from the Ecological Monitoring Centre (CSE) in Senegal. However, to achieve the research's aim, this paper takes all 31 administrative communes to analyze the spatial-temporal evolution of agricultural land transition and its characteristics from 2000 to 2020. The remote sensing data came from various satellites, including Landsat7 ETM + C1, Landsat5, and Landsat8 OLI (Table 1). All the remote sensing images were obtained from the United States Geological Survey (USGS) website with a spatial resolution of 30 m (http://earthexplorer.usgs.gov/).

The collection period of remote sensing images is essential to determining agricultural land accurately. Indeed, Senegal has two main seasons that mark the climatic regime: a dry season from November to April–May and a rainy season from May–June to October, depending on the geographical location (Ecological Monitoring Centre, 2018). Thiès region is one part of the ground basin in Senegal, where the wintering extends from June to October (Sagna Pascal, 2015), coinciding with our study area's rainy season. However, to maximize the characteristics of agricultural land, we chose the winter months to minimize the effects of clouds and seasonal variation. Therefore, according to Feteri et al., the selection of Landsat images was mainly based on availability, cloud cover percentage, and correspondence (Teferi et al., 2013). Due to these constraints, the Landsat images were collected between September and November.

Social survey data and variables explanation

A comprehensive questionnaire for a social survey was designed to collect information about the potential factors affecting the agricultural land transition from the farmers in 11 administrative communes in the Thiès region (Figure 2). In total, 600 questionnaires were collected in October 2022. In addition to this social survey, a field interview was conducted with the commune administrators. Globally, the survey questionnaire was composed of four sections. Only the third section relates to farmers' perceptions of the agricultural land transition's potential driving factors, which this paper explores.

Identifying major underlying factors of agricultural land use transition is essential for developing countries to meet a comprehensive land structure and management. The African continent is growing in importance with climate change and population pressure on land (Home, 2021). As a result, the complex driving factors of agricultural land transition, such as socio-economic (Xian, Li and Qi, 2019) and natural environment (Long et al., 2021) will be used as a reference to evaluate the main agricultural land transition factors. The social and economic variables selected include 1) population growth and 2) urban expansion. In addition, we assume that (3) a lack of investment in agriculture, 4) a suitable land policy, and 5) a high land price may facilitate the agricultural land transition. For this reason, these variables were added to the socio-economic variables to make the research more understandable.

Prior work has highlighted that precipitation (rain, snow, etc.) and temperature determine the potential distribution of terrestrial vegetation and constitute the principal factors in the genesis and evolution of soil (World Meteorological Organization, 2005). The study area has a climate difference in rainfall (Faye et al., 2018). The average rainfall is the main factor for agricultural production and determines the evolution of the sown land area (FAYE Bonoua, 2016). So, our investigation considers 6) rainfall variability and 7) temperature as the main factors affecting the agricultural land use transition. In addition, 8) deforestation, 9) soil salinization, and (10) wind and (11) hydric erosion were also significant variables given

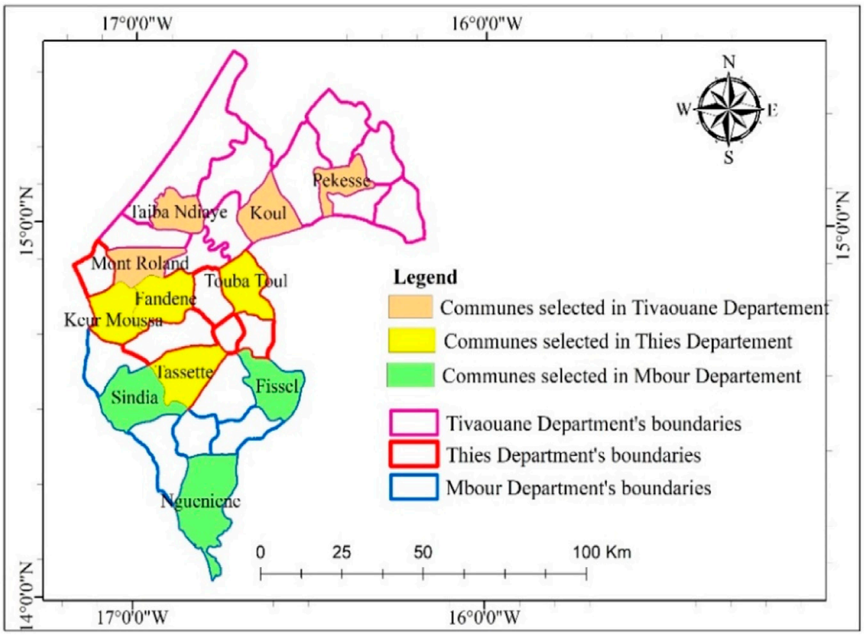

FIGURE 2
The sampling strategy of the social survey in Thiès region, October 2022.

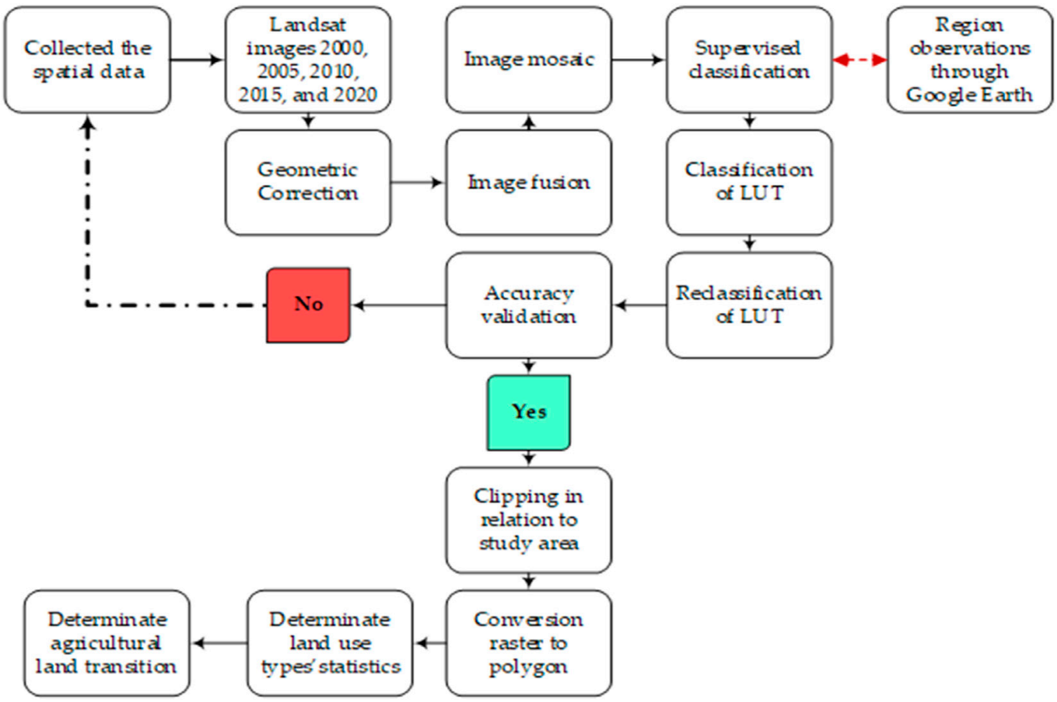

FIGURE 3
The workflow chart of remote sensing image processing.

the topography and forested areas in the study area. Given the complexity of socio-economic development and the natural environment in the Thiès region, 11 variables were selected for this investigation. The CommCare HQ software was used as a tool for collecting data. The face-to-face method was adopted by paying attention to ethical considerations such as sensitive responses like agricultural income. Additionally, the data screening process shows that 15 questionnaires were discarded due to a lack of logic. For this

TABLE 2 Classification method of land use categories.

N	Level I	Level II	Code
1	Agricultural land	Permanent crops; permanent pasture; agro-business landetc.	AL
2	Forested areas	Classified forests, casuarina, nature reserves, mangroves, open forests	FA
3	Grassland	Sparse grass, moderate and dense grassland	GL
4	Wetland	Lakes; permanent water and no permanent water; bottom land, reservoirs, and pond	WL
5	Artificial surfaces	Urban and built-up areas; rural settlements; photovoltaic power generation land; transportation facilities	AS
6	Bare land	Sandy land; ancient mining and quarrying areas; soil salinity; bare land; other lands that are not used until the mapping time)	BL

reason, 585 completed questionnaires were used in the following analysis.

Methods

Given the study area's size, two Landsat images were collected yearly. However, due to the characteristics of the remote sensing data, pre-processing is necessary to have more clarity. Therefore, several steps have been taken, as shown in Figure 3. First, to optimize the quality of the images, the layers were re-projected according to the reference projection system of the study area, which is World Geodetic System (WGS)_1984_Complex_UTM_Zone_28N (EPSG: 31028). This projection allows us to obtain expected results between the processed images. Then, we resampled the remote sensing images to 50 m, the standard resolution for all images (Díaz P. J, 2018). Second, after this geometric correction, such as atmospheric correction, gap fill in Landsat 7 ETM, and image mosaicking through ENVI software. In addition, the supervised classification is chosen for this study, and training samples are selected for each land cover class. Human-computer interaction interpretation methods extracted land use information from the remote sensing image data.

From then on, it is important to note that land use classification systems vary with the purpose and context of their use (Briassoulis, 2020). Consequently, using the classification system of Anderson JR et al. as a reference (Anderson James, 1976), we have reclassified the land use types into six (06) categories: agricultural land, forested areas, grassland, wetland, artificial surfaces, and bare land (Table 2). Additionally, as shown in Figure 3, it is essential to highlight that, during the classification of land use types, Google Earth played a significant role in identifying the unclear characteristics of certain land use morphologies. In addition, the remote sensing images were cut according to the size of the study area. Finally, after the raster conversion to polygons, we used the ArcGIS 10.6 platform to determine land use types' statistics and quantify the agricultural land transition for different periods.

An accurate assessment is essential for processing land use change analysis and classification (Islami et al., 2022). However, the overall accuracy values based on the post-classified images generated for 2000, 2005, 2010, 2015, and 2020 differed yearly. For instance, the least accurate year is 2020, with 0.91. The most significant record is 0.924, which was set in 2005. However, the overall accuracy for our study period was 0.93. Additionally, the kappa coefficient was about 89.05%, indicating that the simulation results have high consistency and accuracy with the actual LULC distribution (Pontius et al., 2008) because an overall standard accuracy for LULC classification is known to be between 85% (Anderson James, 1976).

Tracing sources and flow of agricultural land

Tracing the sources and flows of agricultural land can assist in determining how agricultural land is lost or gained from other types of land (transfer in or out) (Kumar Sathees, 2014). So, this process has followed many steps. Firstly, we introduced the land-use transition matrix to calculate land-use types' transition characteristics. The transition matrix reflects the transferred-out area at the initial period and the transferred-in area at the end period. The following equation was used to calculate the transition matrices:

$$Sij = \begin{vmatrix} S_{11} & S_{12} & S_{n21} \\ S_{21} & S_{22} & S_{n22} \\ S_{n1} & S_{n2} & S_{nn} \end{vmatrix} \tag{1}$$

where n represents the land use type before and after the transfer; i, j (i, j 1, 2. . ., n) represents land use type before and after the transfer, respectively; Sij represents the land use area i land type before transition to type j land type after transition.

Secondly, use the transfer matrix to determine the agricultural land amount and the net transition area transfer. Then, based on the above steps, the amount of "transition reduction" or "transition gain" in the net transition area of agricultural land types in different periods was calculated according to the equations above. The specific formula is as follows:

$$AL_{loss\ (i),j=}\frac{AL_{i,j}}{\Delta AL_I}\ X\ 100\, i \neq j,;\ AL_{gain\ (i),j=}\frac{AL_{i,j}}{\Delta AL_I}\ X\ 100\, i \neq j, \tag{2}$$

$$ALN_{loss\ (i),j=}\left(AL_{j,i} - AL_{i,j}\right) / \left(AL_i - AL_i\right) x\ 100\, i \neq j, \tag{3}$$

Where $ALloss_{(i),j}$ is the ratio of areas converted from agricultural land to land use type j $AL_{(i),j}$ to the total areas of all types of land converted from agricultural land in the year i (ΔALi). $ALgain_{(i),j}$ is the ratio of areas of land use type i converted to agricultural land (ALi,j) to the total areas of all types of land converted to agricultural land in year j (ΔALj). Here j refers to the column number, and i refers to the line number in the land transition matrix. Both $ALloss_{(i),j}$ and $ALgain_{(i),j}$ are contribution rates of land use of certain types converted to out of or to agricultural land. $ALNloss_{(i),j}$ refers to the net transition rate of agricultural land contributed by land use type j, calculated as the ratio of the net converted area from land use type j to agricultural land $(ALj,i - ALi,j)$ to the total net converted land areas to agricultural land in the year i $(AL.i - ALi.)$ (Li et al., 2021).

Analysis of agricultural land transition's temporal evolution

The temporal evolution of the dynamic index of land use change was expressed to measure the rapidity of land use transition (Hossein Talebi Khiavi, 2021). It refers to the rate at which specific land use changes over time (Du Guoming, 2018). So, the following Eq 4 was used in this study to show the rate of change (increase or decrease) of a type of agricultural land use over the study period.

$$V = \frac{Sb - Sa}{Sa} x \frac{1}{T} x100 \quad (4)$$

Where V was the evolution speed of agricultural land use types during the study period, Sa was the land area at the beginning of the study period; Sb was the land area at the end of the study period, and T was the time interval of the study years.

Analysis of agricultural land transition's spatial evolution

The spatial evolution of land use change is frequently characterized by amplitude. In this study, the amplitude of agricultural land net transition evolution was mainly characterized by the value of change in the quantitative transition of agricultural land. It was measured according to the land area of each commune. The equation below 5) determines the spatial index of agricultural land use change (Mohamed and Worku, 2019).

Additionally, several methods have been applied to understand the intensity of agricultural land transitions (Xian, Li and Qi, 2019). Hence, for a comprehensive understanding of the intensity of agricultural land transition, this study chooses the scenario of net transition of artificial surfaces for measuring the intensity of agricultural land transition according to the total size of each commune. This choice is justified by urbanization's continuous loss of agricultural land (Beckers et al., 2020). In other words, the irreversible farmland transition to built-up land occurs globally (Skog and Bjørkhaug, 2020). So, to accomplish this investigation, Eq 5 was also used to describe this intensity.

$$B_{it+n} = \left[\frac{(U_{it+n} - U_{it})}{T} * 100 \right] \quad (5)$$

Where: $Bi\ t + n$ is the annual expansion intensity of spatial unit i; $Uit + n$ is land use types area at the spatial unit i at time $t + n$; Ui t is land use area at the spatial unit i at time t, and T is the land area of at the spatial unit i.

Measuring the degree of spatial balance or imbalance of agricultural land transition

The equilibrium degree of transition is an index to characterize the equilibrium degree of agricultural land use following a change among regions. Several methods exist to appreciate the equilibrium distribution of two or many variables. The simple linear regression model was used in this study to assess the degree of balance or imbalance in agricultural land transition. The horizontal axis *(X)* represents the cumulative percentage of agricultural land net transition, and the vertical axis *(Y)* represents the cumulative percentage of communes.

$$y_i = B_i x_i + \epsilon_1 \quad (6)$$

where yi is an unobservable variable, $\boldsymbol{x}\ i$ is a vector of independent variables, $\boldsymbol{\beta}\ i$ is an array of parameters to be estimated, and εi is the random error term assumed to be distributed as a standard normal. The index denotes the ith household (Vixathep S, 2013).

In addition to the simple linear regression model, the coefficient of variation *(CV)* was calculated to appreciate the dispersion of agricultural land net transitions from one period to another. It is a statistical measure of how far apart the points in a data set are from the mean.

$$CV_{ij} = \frac{SD._{ij}}{NM._{ij}} \quad (7)$$

Where $CVij$ represents the value of agricultural land use transition to other land use types in county i during period j, where SD is the standard deviation of the data sample, MN is the average value of the data sample values of the CV related to whether and how to balance the set of results is spatially distributed.

Assessment of the farmer's perception of the drivers' factors of agricultural land transition

In this study, to understand the drivers' factors of agricultural land transition, the variables ranged from "strongly agree," "agree," "neutral," "disagree," and strongly disagree." This study chooses only the frequency of "strongly agree" for assessing the driving factors. Relevant studies target the social, economic, and natural factors that caused the agricultural land transition. This study used the method of intercorrelation between the variables to understand the phenomenon according to the farmer's perception. Hence, there are several methods of calculating correlation. The most common form, the Pearson product-moment correlation, was used in this study, as shown in Equation (8). As a result of the autocorrelation, it is possible to conduct a holistic evaluation and hierarchy of the factors and their order of importance in agricultural land transition.

$$r = \frac{n^* (\sum X, Y) - (\sum (x)^* \sum (y)))}{\sqrt{(n^* \sum (x^2) - \sum (x)2)^* (n^* \sum (y^2) - \sum (y)2)}} \quad (8)$$

Where r = correlation coefficient; n = the number of observations of the eleven communes selected for the social survey. The Pearson correlation coefficient ranges from *-1* to *+1*. When the coefficient = *0*, there is no linear correlation; when the coefficient = *+1*, there is a perfect positive linear correlation; and the coefficient = *-1*, there is a perfect negative linear correlation.

Results

Quantify the agricultural land use transition

The results presented in this section differed from one period to another (Table 3; Figure 4). Between 2000 and 2005, agricultural land use decreased by about −303.01 km^2. During this period, forested areas (168.55 km^2) were the most common land use type, resulting in the loss of agricultural land. Also, artificial surfaces accounted for 40.22 km^2 of this lost value. The situation remained similar in the second period (2005–2010) due

TABLE 3 Statistics of agricultural land net transition for 2000–2005, 2005–2010, 2010–2015, and 2015–2020.

Period	Land use types	Transfer in (Gain)	Transfer out (Loss)	Net Transition	Temporal index	Spatial index
2000–2005	Agricultural land	24.07	327.07	−303.01	−4.41	−4.54
	Artificial surfaces	53.19	12.96	40.22	14.77	0.60
	Forested areas	246.15	77.60	168.55	10.34	2.52
	Grassland	85.41	18.89	66.51	16.76	0.99
	Bare land	91.90	167.15	−75.25	−2.14	−1.12
	Wetland	117.81	14.83	102.98	33.06	1.54
2005–2010	Agricultural land	940.99	1214.2	−273.29	−1.07	−4.09
	Artificial surfaces	75.69	61.42	14.26	1.10	0.21
	Forested areas	403.00	668.72	−265.72	−1.89	−3.98
	Grassland	1214.01	460.07	753.94	7.80	11.30
	Bare land	521.30	628.68	−107.38	−0.813	−1.60
	Wetland	13.36	135.17	−121.81	−4.29	−1.82
2010–2015	Agricultural land	1017.63	1127.68	−110.05	−0.46	−1.65
	Artificial surfaces	93.81	42.56	51.24	5.73	0.76
	Forested areas	854.16	389.85	464.30	5.67	6.96
	Grassland	355.37	1263.04	−907.68	−3.42	−13.60
	Unused land	897.68	432.03	465.65	5.13	6.98
	Wetland	53.93	17.37	36.55	10.01	0.54
2015–2020	Agricultural land	1269.56	1149.99	119.56	0.50	1.79
	Artificial surfaces	112.14	68.92	43.22	2.98	0.64
	Forested areas	293.99	702.12	−408.13	−2.76	−6.11
	Grassland	845.14	442.01	403.12	4.34	6.04
	Bare land	677.50	792.98	−115.49	−0.69	−1.73
	Wetland	25.24	67.53	−42.29	−2.98	−0.63

to agricultural land losses of approximately −273.29 km^2; grassland was the primary contributor to the total loss. Compared with the two first periods, the agricultural land transition diminished from 2010 to 2015. The net transition of agricultural land was −110.05 km^2 or a difference of 193.05 km^2 compared to 2000–2005. Hence, the agricultural land net transition was intense from 2000 to 2005. Similarly, 2015–2020 shows that agricultural land was gained among the other land use types, with 119.56 km^2. As shown in Table 3, except for one period, this study's inter-period results revealed that the net transition of agricultural land was negative, whereas grassland gained the mean important flow.

The study period may produce noticeable results regarding agricultural land transition. This analysis shows the total net agricultural land transition was about −566.80 km^2. With 315.90 km^2, grassland represented the most significant flow. With 167.51 km^2, bare land came in second place. Artificial surfaces are the most common land use type that may threaten agricultural land, accounting for approximately 148.95 km^2. In summary, over the past 21 years, the most considerable change has been the substantial transition of agricultural land with a −1.667% temporal index, of which grassland has represented the most critical land use that caused this transition (Table 4).

Analyze the spatial distribution of net transition agricultural land

The spatial analyses of the net transition of agricultural land at an interval level, as shown in Figure 5, revealed several aspects. In fact, with a variation coefficient of −0.71%, agricultural land dropped in all the communes in the first period (2000–2005). The highest negative value of net conversion was recorded in the Mbayenne commune (−0.65%) and the least in the Noto G. Diama commune (−12.35%). In these communes, bare land gained about 6.14 km^2 in Noto G. Diama and 0.20 km^2 in Mbayenne. The coefficient variation was - 4.68 from 2005 to 2010, with Thieneba at −24.22% and Keur Moussa commune at 40.06% of the net transition of agricultural land. From 2005 to 2010, the average net transition of agricultural land was around −1.26 km^2, higher than the first period, which recorded −4.51 km^2. Then, the net

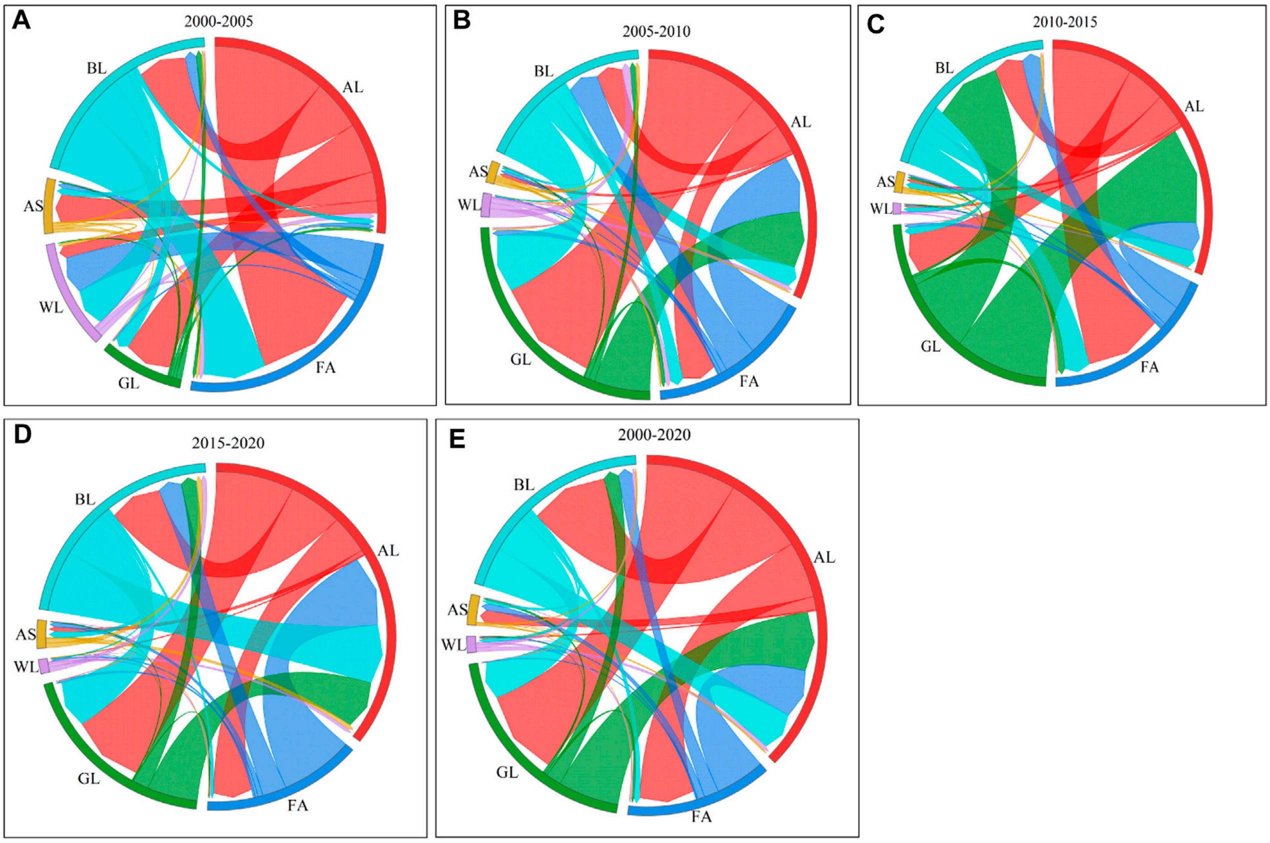

FIGURE 4
(A–D) shows the land use types transition sources and flows in 2000–2005, 2005–2010, 2010–2015, and 2015–2020, respectively, and **(E)** shows the study period of 2000–2020; with (AL) Agricultural land, (WL) Wetland, (AS) Artificial Surfaces, (FA) Forested areas; (GL) Grassland, and (BL) Bare land in Thiès Region.

TABLE 4 Land use matrix in Thiès region (km²) from 2000 to 2020.

Land use types in 2000	Land use types in 2020							
	Agricultural land	Artificial surfaces	Forested areas	Grass land	Bare land	Wet land	Total - 2000	Loss
Agricultural land	2178.49	87.18	380.81	601.80	540.17	8.82	3797.27	1618.7
Artificial surfaces	10.44	59.68	1.14	1.91	9.46	0.24	82.87	23.19
Forested areas	335.48	47.29	282.26	5.26	98.77	6.94	776.00	493.75
Grassland	411.70	14.95	16.73	360.66	102.51	1.25	907.81	547.15
Bare land	266.79	20.58	40.35	253.86	403.56	23.57	1008.71	605.14
Wetland	27.57	2.14	13.71	0.23	21.74	30.46	95.85	65.38
Total - 2020	3230.48	231.82	734.99	1223.71	1176.21	71.29	6669.51	—
Gain	1051.98	172.14	452.73	863.05	772.65	40.82	—	—
Total shift	−566.80	148.95	−41.01	315.90	167.51	−55.02	—	—
Temporal index (%)	−1.667	30.589	−0.396	2.749	1.318	−1.789	—	—
Spatial Index (%)	−8.498	2.233	−0.615	4.736	2.512	−0.368	—	—

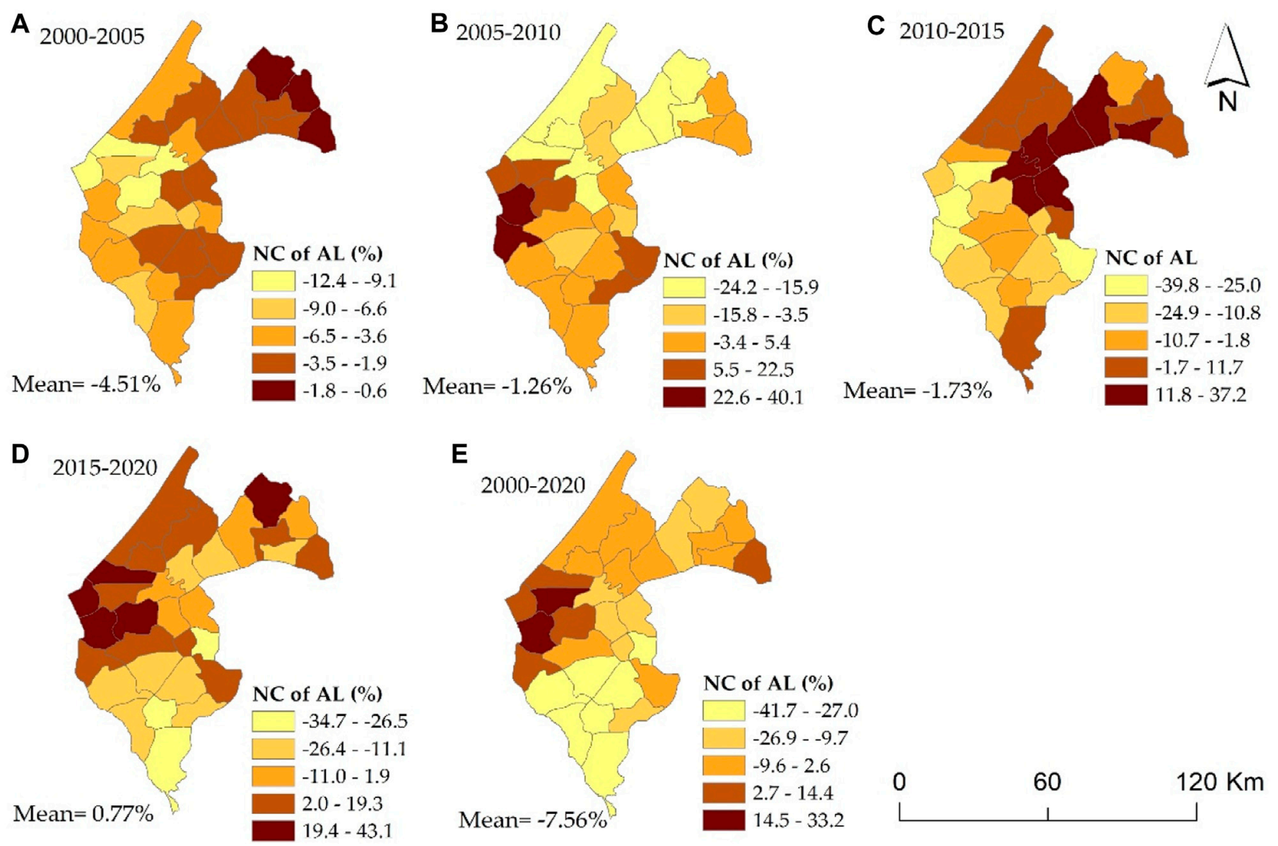

FIGURE 5
(A–D) shows the Spatial distribution of Net Transition of Agricultural Land (NC of AL) in 2000–2005, 2005–2010, 2010–2015, and 2015–2020, respectively, and **(E)** shows the study period of 2000–2020 in Thiès region, Senegal.

transition of agricultural land from 2010 to 2015 was similar to the above description. This period records a coefficient of variation of about −10.23 with an average net transition of −1.73 km^2. These cases were −39.81% in the commune of Mont-Rolland and 37.20% in the commune of Koul. In Koul, bare land contributes approximately 41.03 km^2; in Mont Rolland commune, forested areas dominate 81.06 km^2 for this transition. From 2015 to 2020, the net transition was 43.09% in Noto G. Diama, compared to −34.73% in Sandiara. The coefficient of variation was 25.03 from 2015 to 2020.

During the study period (2000–2020), the coefficient of variation was about −2.22 (Figure 6). The spatial distribution of the net transition of agricultural land was in Mont Rolland commune, at approximately 33.22%. In this amount, forested areas lost about −43.99 km^2, which appears to have been the more common land use type during the agricultural land transition. In the Sandiara commune, the spatial distribution was −41.73%. Bare land was the most critical land use category, contributing to the loss of agricultural land at approximately 55.52 km^2. With an average of −7.56%, the agricultural land transition remained unequally distributed in the Thiès region from 2000 to 2020. In sum, Figure 5B highlights the relatively substantial dispersion. In other words, they are not significantly correlated regarding agricultural land transitions between the communes. The R^2 coefficient was 0.3964 from 2000 to 2020. Consequently, it appears that the potential driving factors may be different.

Analyze the temporal distribution of net transition agricultural land

The temporal distribution of agricultural land net transition was nearly identical for all communes between 2000 and 2005, with an average of −15.53% (Figure 7). The temporal evolution of the net transition of agricultural land was −13.55% in the Ndiass commune and −16.69% in the Darou Khoudouss commune. From 2005 to 2010, Touba Toul commune recorded the highest temporal index of 303.62%. Or, compared with the average period (26.55%), the lowest speed was localized in Marouane commune, approximately −14.17%. From 2010 to 2015, the average temporal index was around 15.95%. Hence, this average has many characteristics because about 140.09% of net conversion is noted in the Koul commune, compared to the lowest of −15.84% in the Mont-Rolland commune. In contrast to the previous period, the speed of 2015–2020 was high, with an average of 17.59%. The highest speed was related to Noto G. Diam (188.17%) and the lowest in Nguiene commune, at −15.22%. In short, the inter-period analysis of the time distribution of the agricultural land net transition showed that the speed varied from commune to commune.

The study period was better analyzed to understand the characteristics of agricultural land's net transition. The average speed from 2000 to 2020 was approximately 0.072%. This average hid several disparities within the commune. Twenty of

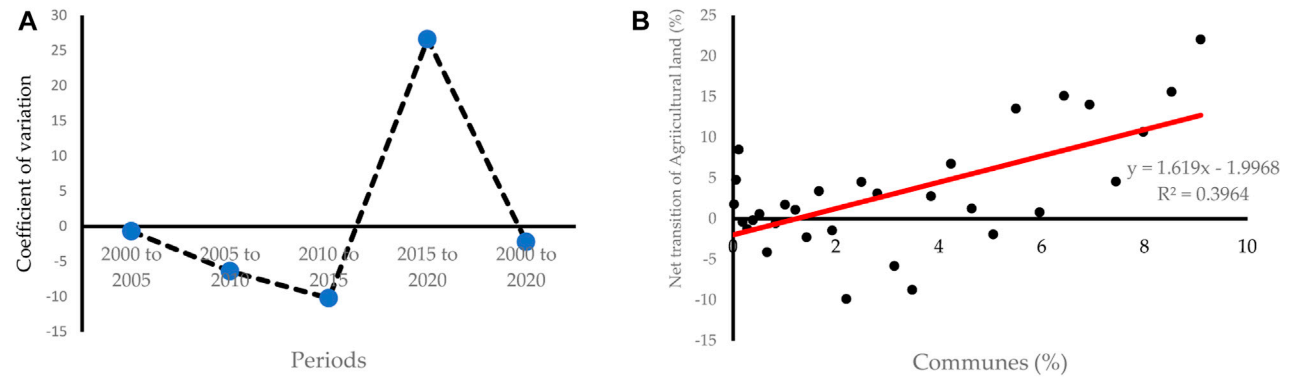

FIGURE 6
Measuring the degree of spatial balance or imbalance of agricultural land net transition **(A)**, variation's coefficient, **(B)** linear regression from 2000 to 2020.

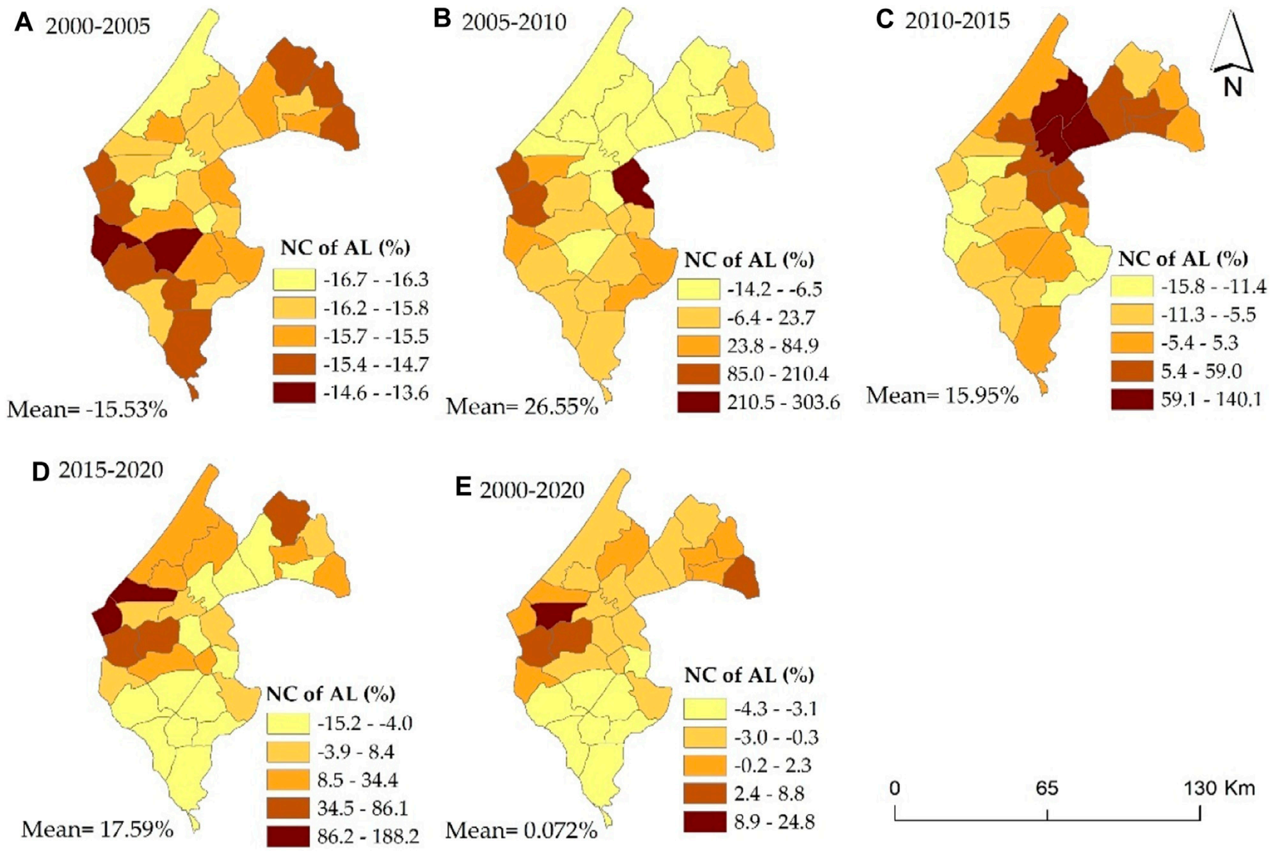

FIGURE 7
(A–D) shows the Temporal distribution of Net Transition of Agricultural Land (NC of AL) in 2000–2005, 2005–2010, 2010–2015, and 2015–2020, respectively, and **(E)** shows the study period of 2000–2020 in Thiès region, Senegal.

the thirty-one communes investigated presented a negative speed. This negative value was located in Koul (−0.35%). Or, at −4.33%, the Sandiara commune had the slowest speed. The Mont Rolland commune (24.84%) recorded the most critical speed among the communes, recording a gain. Or, the commune of Pekess presented less speed by 0.18%. In this amount, Mont-Rolland recorded a net transition of agricultural land of 56.00 km^2 and Sandiara of −60.41 km^2. As a result of this analysis, despite the study being conducted in the same area, the spatial and temporal repartition of the net transition of agricultural land in the Thiès region displayed several characteristics that could be attributed to various economic and social factors.

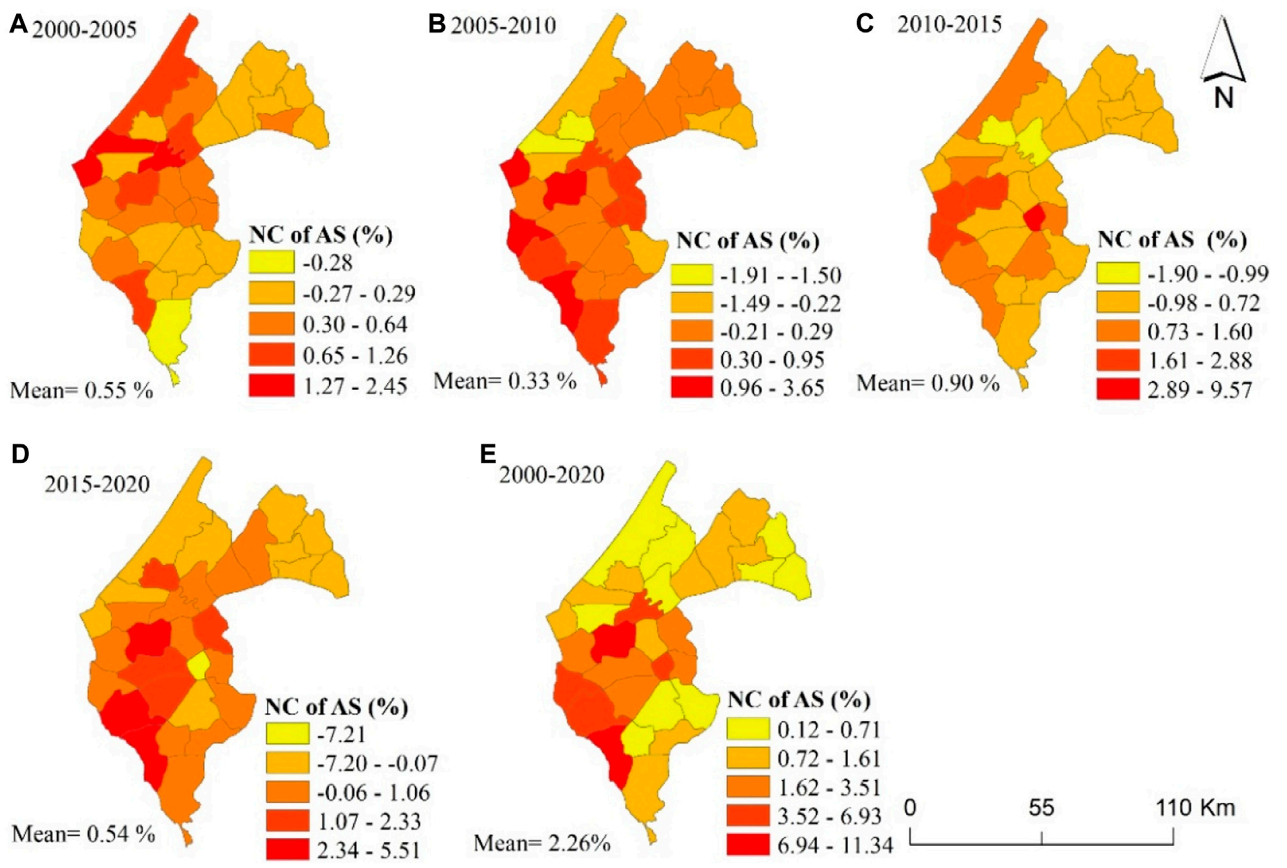

FIGURE 8
(A–D) shows the spatiotemporal intensity index for the transition of Agricultural Land (ALI) measuring according to the Net Conversion of Artificial surfaces (NC of AS) in 2000–2005, 2005–2010, 2010–2015, and 2015–2020, respectively, and **(E)** shows the study period of 2000–2020 in Thiès region, Senegal.

Evaluated the intensification of agricultural land transition

This section examines the intensity transition on agricultural land. In fact, from 2000 to 2005, the rate of artificial surface conversion was 2.50% in the Noto G. Diama commune. The conversion of agricultural land to artificial surfaces covered approximately 4,006 km^2 in this commune. Similarly, Cherif Lo (1.81%) and Diender Guedj (1.91%) achieved high results. The proportion of agricultural land in this net transition of artificial surfaces was 2.63 km^2 and 2.45 km^2, respectively. Alternatively, the net transition of artificial surfaces in Ngueniene commune was −0.28%, and the cause of the decrease in artificial surfaces was wetland by 1.26 km^2. Between 2005 and 2010, the Malicounda commune experienced an essential transition of 3.65%. Fandene commune occupied second place with 2.21%. Malicounda lost approximately 6.45 km^2 of agricultural land to the profile of construction land, while Fandene lost about 1.55 km^2. We noted that eight communes recorded a negative value during this period—for instance, Mont-Rolland commune −0.055%—and bare land contributed to this loss.

As shown in Figure 8, from 2010 to 2015, the average intensity was 0.9%. The highest intensity of artificial surfaces was localized in Ngoudiane commune at 9.57%. This percentage was the highest for all the previous periods. Agricultural land (2.46 km^2) and bare land (3.5 km^2) represented the land use types that contributed to the significant value of construction land. The intensity was lowest in Taiba Ndiaye commune (−19%), whose bare land (3.05 km^2) has caused this phenomenon. Between 2015 and 2020, the results in Malicounda (5.51%) showed diminished intensity compared to the previous period. In this commune, agricultural land losses add about 3.38 km^2 to the profile of construction land. Then, the Sindia commune occupied the second place at approximately 4.52%, and the loss of agricultural land to the artificial surfaces profile was more critical than in the Malicounda commune, with 5.97 km^2. Globally, the inter-period results show that the artificial surface intensity is moderately high. Even though the causes and effects of this change are different, we thought that the amount of agricultural land turned into artificial surfaces was significant.

The study period was a comprehensive pivot to understanding the global intensity of the net transition of construction land. The Malicounda commune records the highest value at 11.34%. In this commune, agricultural land loss to artificial surfaces was about 20.20 km^2. This loss from agricultural land to artificial surfaces was approximately 8.79 km^2 in Fandene and 11.99 km^2 in Sindia commune, with an intensity of 9.82% and 6.93%, respectively. Or, the Thilmakha commune (0.1%) records the lower net transition, and the loss of agricultural land to artificial surfaces was about 0.296 km^2. Globally, 31 communes were registered, with 15 having a percentage higher than

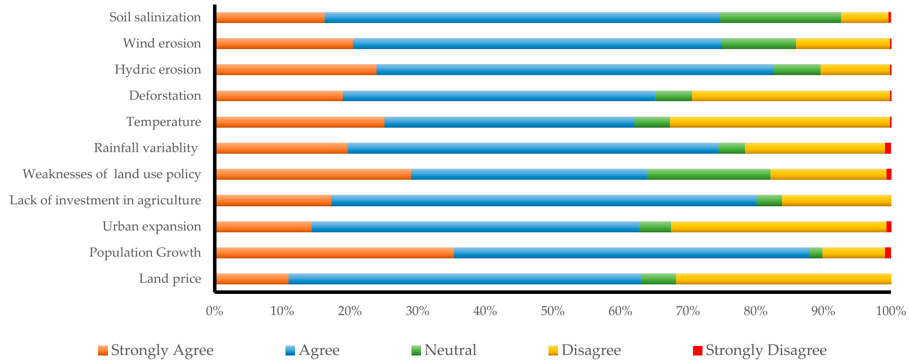

FIGURE 9
Farmer's perception of the potential driving forces of agricultural land transition in Thiès region.

1%. Geographically, these communes were located southwest of and central to our study area (Figure 8E). Consequently, this study's transition from agricultural land to artificial surfaces was significant. Therefore, the influence of bare land on the net transition of construction and agricultural land is not negligible and needs a comprehensive investigation.

Farmer's perception of agricultural land transition

A growing body of literature agrees that socio-economic development occurred during the agricultural land transition (Kanianska, 2016). Conversely, according to farmers' perceptions, natural environmental factors drive the agricultural land transition. Firstly, as shown in Figure 9, if we focus on the "strongly agree" response, the socio-economic factors, namely, the population growth factors (35.38%), record the most important "strongly agree" response among the other driving factors. Weaknesses follow it in the land use policy factor (29.06%), considered a political driving factor. Regarding natural and climatic factors such as temperature and hydric erosion, they recorded 25.13% and 23.93%, respectively. Secondly, Table 5 showed that the relationship between soil salinization and deforestation was the most significant, with 0.971. In the same sense, wind erosion and soil salinization (0.944) occupied the second place. In that setting, the main driving factors that may facilitate the agricultural land transition in Thiès' region are the natural environment and biophysical factors. Alternatively, among socio-economic factors, one of the most interesting results was observed between the lack of agricultural investment and land policy (0.695). This context was followed by land policy and land prices (0.586). The lower value (0.246) was observed between urban expansion and population growth. Consequently, it seems that the manifestation of agricultural land transition is not the same between industrial and developing

TABLE 5 Assessment of the farmer's perception of the potential driving factors of agricultural land transition in the Thiès region.

	1	2	3	4	5	6	7	8	9	10
Land price	x									
Population growth	0.362	x								
Urban expansion	0.378	0.246	x							
Lack of investment in Agri	0.819	0.614	0.446	x						
Land policy	0.586	0.570	0.380	0.695	x					
Rainfall variability	0.813	0.507	0.540	0.893	0.714	x				
Temperature	0.801	0.633	0.648	0.793	0.861	0.835	x			
Deforestation	0.838	0.600	0.699	0.821	0.671	0.897	**0.938**$^{(4)}$	x		
Hydric erosion	0.463	0.502	0.636	0.502	0.492	0.587	0.659	0.697	x	
Wind erosion	0.691	0.661	0.794	0.822	0.739	0.875	0.925	**0.943**$^{(3)}$	0.760	x
Soil Salinization	0.735	0.555	0.813	0.715	0.611	0.837	0.906	**0.971**$^{(1)}$	0.690	**0.944**$^{(2)}$

Note: Bold represented the coefficients are significant.
p-value $^{1)}$ = $p > 6.8E\text{-}07$.
p-value $^{2)}$ = $p > 1.2E\text{-}05$.
p-value $^{3)}$ = $p > 1.40E\text{-}05$.
p-value $^{4)}$ = $p > 2.0E\text{-}05$.

countries. In conclusion, farmers' perceptions of socio-economic drivers of agricultural land transition in this region are insignificant compared to natural environmental drivers.

Discussion

Economic driving mechanism

According to the findings of this study, between 2000 and 2020, a diverse range of factors, including those related to the economy, politics, and nature, may significantly impact Thies region's agricultural land morphology. An in-depth exploration of the dynamics and existing problems in farmland morphology is crucial to formulating targeted protection policies (Lyu et al., 2021). Therefore, understanding agricultural land use dynamics in transition is critical for ensuring national food security in developing countries like Senegal. The agricultural land resource is an indispensable production factor for national economic development and farmer households. Economic growth generally leads to increased demand for land and changes in land utilization patterns (Chen et al., 2020). This situation is a reality in Thiès because the results show that between 2000 and 2020, the net transition of artificial surfaces was about 148.95 km^2 and evolution of 210.7%. According to ANSD, between 1976 and 2019, the regional urbanization rate increased steadily from 29% to 51.7%, respectively. Then, Thiès region has served as a secondary region of Senegal to promote socio-economic development (Faye and Du, 2021). Promoting socio-economic development requires constructing new infrastructure, and the lack of comprehensive land policies may induce agricultural land transition. This context is essential because fast urbanization appears to be a factor that may induce the transition of agricultural land. Expansions of housing, transportation, industry, retail sales, schools, and other developments are driving farming off of land (Francis et al., 2012). The analysis demonstrates that the communes of Fandene (Department of Thies) and Malicounda (Department of Mbour) have the most intense agricultural land transition. Or, in the North, the agricultural land use seems to have been caused by other factors such as climatic according to the survey. Then, the rural exodus and other economic activities, such as tourism in the western part of the Thies region, partly explain this rapid increase in the urban population. The majority of the population and economic activity of the Thiès region is concentrated in these communes, which serve as the city centers. The migration percentage for employment problems represents 13.3% in the Thies region for ages 15–35. Accordingly, the migration led almost to urban spatial issues and agricultural land abandonment. So, as cities grow and spatially expand in the Thiès region, agricultural land is converted into residential land (Picard and Selod, 2020).

In addition, the Thiès region was one of the backbone regions of Senegal's mining industry. Previous studies highlight that mining activity in the northern part of the region, such as Taiba Ndiaye commune, strongly impacts the population's socio-economic life (Henri Marcel SECK, 2021), including agricultural land use. So, this situation can justify the rapid conversion of agricultural land use to bare land in this part of our study area. Regarding infrastructure, this area has been chosen to host significant structuring projects such as Blaise Diagne International Airport and the Special Integrated Economic Zone. In addition, there are the urban poles of Diamniadio and Lac Rose, the industrial zone of Diamniadio, and the motorway projects. In this situation, the demand for land became more and more significant. The survey results did not highlight this spatial pressure on land, which revealed the lowest relationship between urbanization and population growth at 0.246. Thus, there is uncertainty regarding the influence of urban expansion on agricultural land transition. As a result, the social survey results demonstrate that urbanization was most significant in the western part of our study area, like the Sindia commune. This region's part of the west appears to have the highest urbanization because of its proximity to Dakar (the capital of Senegal). In 2017, the Dakar region accounted for 39.5% of Senegal's economic units, whereas Thiès and Diourbel accounted for 11.5% and 9.9%, respectively (Ministry of Economy Finance and Planning, 2017). In short, based on the spatial and survey data, we thought that the link between rapid urbanization and population growth might cause the rapid change from farmland to no agricultural land in our study area.

Land policies and cultural driving mechanism

This section's policies and cultural driving factors are the dualities between state land use policies and traditional land use practices. Since the Industrial Revolution, the economic development of Western Europe and North America has been characterized by continuous urbanization accompanied by a gradual phasing-in of urban land property rights over time (Cai Yongyang, 2015). Conversely, in developing countries such as Senegal, urbanization has been accompanied by several conflicts. The issue is the competition between land users, weak land tenure, etc. For instance, the drastic loss of livelihoods, including agricultural land, in the peri-urban areas of Sebougou (Mali) is primarily related to the crisis in Mali's land management system (Coulibaly and Li, 2020). So, the agricultural land transition process may be more complex in Senegal than in industrial countries. The weak land use plan may significantly affect the rapid agricultural land transition. For instance, the duality between customary and modern land policy led to many issues in Thies. A relevant study highlights that on the West African continent, the land is mainly accessed through an informal and customary channel (Durand Lasserve and Selod, 2013). So, converting agricultural land use to another no agricultural land activity became more significate. This assertion shows that land on Thies region remains subject to traditional practices.

Land tenure is closely related to culture and institutional values in society (Suryadi et al., 2021). In Senegal, Law N*64–46 of 17 June 1964, governs land use management in Senegal and stipulates that land belongs not to the state, territorial communities, or users but to the "Nation" (Niang, 2017). In other words, this law stipulates that most of the land in Senegal is national domain land that does not belong to the people who use it because the law has abolished customary rights. According to the National Agency for Demography and Statistics, approximately 88.61% of plots were not registered between 2017 and 2020. This situation shows that agricultural land remains under traditional dominance, and the mode of land acquisition is passed down from generation to generation. As a result, landholders can sell, transfer, or reuse it for other purposes without significant legal constraints. Hence, no registered land became an obstacle not only to agricultural development but also caused rapid urbanization (Faye, Du and Zhang, 2022). Accordingly, the continuous fragmentation of agricultural land from generation to generation without an adequate policy for its protection remains a reality. So, the dominant morphology changes in Senegal, particularly in the Thiès region, is heavily influenced by property rights and a lack of agricultural investment. In another work, the lack of land policies is often seen as the main factor in agrarian land transitions. Political and economic reforms are imperative for farming and related sectors. But today, it is difficult for developing countries like Senegal to initiate specific reforms. This situation arose because the politic of decentralization, for example, remains closely linked to the obligations of structural adjustment policies and is constrained by the logic of liberal reform (Boutinot, 2003). Then, according to FAOSTAT data, over the period 2000–2020, the average credit to agriculture was about US $48.82 million. This situation seems to indicate that external financial institutions partly finance Senegalese agriculture. As a result, the agricultural policy reforms, including Senegal's land system, remain challenging and complex. In summary, this may imply that when the social development level is low due to the unclear property rights of cultivated land and underdeveloped agricultural technology, the social awareness of cultivated land protection is relatively weak, and cities are disorderly expanded (Lv et al., 2022).

Natural environment driving forces

This study's main factors are natural factors such as rain variability, deforestation, and temperature. Rain variability has a significant impact on the evolution of sown land use. In fact, in Africa, particularly in the Sahel, after the rainy periods of the 1960s, many researchers noted rain anomalies in the early 1970s (Ambiente, 2016). This situation was pointed out, too, in Senegal. Tappan et al. (2004) revealed that rainfall in the Groundnut Basin ranged from 400 to 800 mm in the 1960s to 200–600 mm in the 1990s (Tappan et al., 2004). Then, according to the data collected by the National Agency for Civil Aviation and Meteorology (ANACIM), the average rainfall from 2000 to 2020 was 461.65 mm. Or, this average hid several disparities. For instance, in 2000, the average was 607.90 mm, compared with 317.90 mm in 2005. These analyses show a difference of 290 mm. The above discussion shows that rain remains a problem in our study area because Senegal's agricultural production still depends entirely on the rainy season. This variability's consequences are reflected directly in farm productivity and yield (FAYE Bonoua, 2016). In addition, low annual rainfall, frequent dry spells, and the shortening of the rainy season affect the vegetative cycle of crops (Faye Mbagnick, 2018). During the social survey, several farmers attested that their agricultural land was decreased, and the most critical factor was rainfall, weak agricultural investment, and so on. Therefore, weak agricultural productivity diminishes agricultural land area, directly inducing agricultural land abandonment and population migration. This is because agriculture is Senegal's main activity (ANSD, 2020). The household, affected by the weak agricultural productivity, moves to a big city such as Dakar to look for new activities. This statement may explain the strong relationship between rainfall and lack of investment in agricultural land (0.893). However, agricultural production depends on rainfall (Isabelle et al., 2019) and the availability of outputs. In the same sense, the temperature data from the same period from 2000 to 2020 reveal that in 2000 the average temperature was 24.85°, and in 2020 it was 28.01°. So, the temperature was gradually rising. This augmentation of the temperature seems to have a negative impact on agricultural land use, as shown by the survey results (0.971).

Desertification is land degradation in drylands resulting from various factors, including climatic variations and human activities (European Union, 2011). In other words, land use and cover changes, such as deforestation, affect the climate system and land-atmosphere interactions (Sy et al., 2017). In that context, agricultural land transition and deforestation will be inextricably linked. This assertion was supported by our research, which discovered that the net change of agricultural land and the net transition of forested areas decreased during the study period. The social survey results indirectly show a high relationship between deforestation and wind erosion (0.943). This relationship induces subsequent socio-economic consequences, such as agricultural productivity. Relevant studies show that rural economic development (Liu et al., 2014) and urbanization (Rondhi et al., 2018) are the primary forces driving the transition from farmland to non-agricultural land use. As revealed by the social survey, the relationship between rainfall variability and deforestation was strong (0.897) from then on. Furthermore, according to survey results, many smallholders believe the garden could be an excellent solution for dumping this matter in the event of less rain. In contrast, the lack of financial means is critical for obtaining the solution. In addition, to support their families, many sell agricultural land or choose migration to diversify their income. So, this practice was seen as facilitating agricultural land transition and fragmentation.

Bio-physical driving forces

Natural factors like rain runoff and bio-physical drivers like hydric erosion are closely linked. Hence, the consequences of the decrease in rainfall are reflected in Senegal by the degradation of the natural environment. Then, drought leads to the degradation of the vegetation cover, the soils being subjected to erosion and runoff, and the accentuation of acidification and salinization (Ndong, 1995). Hence, Senegal's forests have decreased from 4.4% in 1965 to 2.6% in 2000 (Tappan et al., 2004). Similarly, our results show that forested areas have dropped by −41.01 km^2. In that setting, the forested areas in Senegal continue to be reduced. Consequently, forest degradation may affect agricultural land quality because previous studies have highlighted that soil organic carbon is crucial in regulating soil quality functions and ecosystem services (Amoakwah et al., 2022).

Multiple physical, chemical, and biological degradations increasingly threaten the soil. Soil erosion affects 56% of the land surface worldwide (Van Oost et al., 2007). Specifically, soils in Africa affected by moderate to severe water erosion cover more than 12 million hectares, or 18.5% of the total national territory (Faroukh Tsouli A, 2017). Then, the Groundnut Basin of Senegal (including our study area) is confronted with chemical and physical-biological degradation, which has become more intense. Thus, the

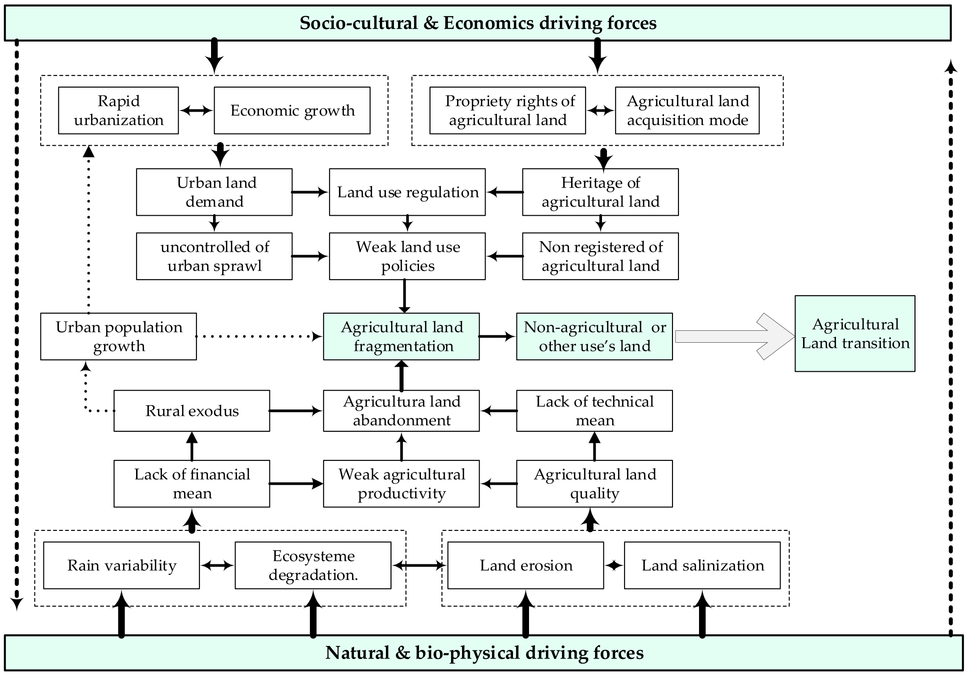

FIGURE 10
The flowchart summarizing the discussion section of the study.

soils are impoverished, restructured, and chemically exhausted by wind, water erosion, and recurrent droughts (Reseau Agro-Innov, 2017). The survey results show that the relationship between soil salinization and hydric erosion was about 0.690. This situation signifies that biophysical driving forces like wind and water erosion are some of the main factors that may facilitate the agricultural land transition in the Thiès region.

Consequently, agricultural land degradation was occurring in Senegal's Thiès region. This continuous degradation may impact agricultural productivity because agricultural soil erosion is thought to perturb the global carbon cycle (Van Oost et al., 2007). Hence, the deterioration of forested areas significantly impacts agricultural land quality. According to the above background, the agricultural land transition is an incentive-driven process (Rondhi et al., 2018). According to the social survey data and the summary in Figure 10, biophysical factors appear to be one of Thies region's most important driving factors that induced agricultural land transition. However, the study clarifies that social, economic, and natural factors are all tied together in the agricultural land change in our study area.

This discussion has shown that the Thiès region's agricultural land faces several driving factors, particularly natural factors, which have been identified as the main factors. From then on, the first recommendation regarding agricultural land protection is implementing a comprehensive land use reform policy. This context exists because implementing clear rules between users is the first key to protecting it. So, according to the complexity of the land management system in Senegal, reforming land tenure must cooperate with its complexity rather than attempt to substitute customary land practices. From an economic point of view, we think that increasing agricultural production, creating new jobs, and raising income may stop agricultural land from changing because, according to survey results and interviews, agricultural land changes rapidly when abandoned or sold.

Conclusion

Agriculture land dominates the Thiès region's land use morphology, accounting for 48% of the total land area. The main objective of this article was to understand the characteristics of the transition of agricultural land in the Thiès region from a quantitative point of view and a spatial and temporal evolutionary point of view. From a quantitative point of view, agricultural land decreased from 2000 to 2020 by −588.66 km^2. Grassland was the most critical land use type to have participated in this loss. Also, the share of Artificial surfaces was about 148.95 km^2 during the same period. From 2000 to 2020, the commune of Mont-Rolland was dominated by spatial characteristics (33.22%). Alternatively, agricultural land use loss in the Sandiara commune is 41.73%. For the temporal distribution, the average speed from 2000 to 2020 was approximately 0.07%. The net transition was negative in Koul, with an amplitude of −0.35%. Or, the commune of Pekess increased its speed by 0.18%. In the end, this analysis shows that even though the study occurred in the same area, the spatial and temporal distribution of the net transfer of agricultural land in the Thiès region had different features. The intensity of agricultural land measured varied from one area to the next due to the net transition of construction land. The intensity was high in Malicounda commune, where the net transition of artificial surfaces was 11.34%. In this commune, agricultural land loss to artificial surfaces was about 20.20 km^2. This loss from agricultural land to Artificial surfaces was approximately 8.79 km^2 in Fandene and 11.99 km^2 in Sindia commune, with an intensity of 9.82% and 6.93%, respectively. With the R^2 about

0.396, they are not significantly correlated regarding agricultural land transitions between the communes. Additionally, the social survey data show a substantial relationship between natural factors and socio-economic drives. The most significant was the nexus between soil salinization and deforestation. In contrast, the relationship was about 0.246 for population growth and urbanization.

This research contributes to using an integrated analysis method to understand the causes of agricultural land transition while highlighting policy flaws that may lead to a rapid agricultural land transition. So, from this contribution, the study also enhances the theoretical approach and methodology for assessing the mean potential driving factors in developing countries such as Senegal. From these results, the policy implications highlighted in this study rank from lessons to strengthen agricultural land use reforms to promoting the awareness of land use policy, particularly agricultural land. Encouraging land consolidation is also urgent to optimize agricultural production and avoid land fragmentation. Consequently, the study highlighted certain limitations that should be addressed in future research. Firstly, the contribution of bare land to agricultural land transition was high. So, future research may focus on the details of the influence of bare land on agricultural land. The natural driving factors were much more visible than the socio-economic driving factors. Alternatively, the population continues to grow rapidly in tandem with socio-economic development. As a result, an in-depth investigation may be required to determine the impact of socio-economic factors on agricultural land transition in the Thiès region.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization, BF and GD; methodology, BF; software, BF; validation, BF, GD, QL, TS, EM, and RZ; formal Analysis, BF; investigation, BF; resources, BF; data curation, BF; writing—original draft preparation, BF; writing—review and editing, BF, GD, QL, TS, EM, and RZ; visualization, BF, and GD; supervision, GD; project administration, DG. All authors contributed to the article and approved the submitted version.

Funding

This research was funded by the National Key R&D Program of China, grant No. 2021YFD1500101.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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