



Research Article



Impact of urban and peri-urban growth on arable land (1976–2029) in a medium sized city of Shire Indaselassie, North Western Tigray, Ethiopia

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Abstract

Urban and peri-urban areas have been growing rapidly globally due to population increase and other factors. However, poor urban land use planning caused remarkable impacts on the loss of potentially arable land. This study aimed to analyze the spatio-temporal patterns of urban and peri-urban expansion and its impact on arable land in the Shire Indaselassie city, North Western Tigray. Multi-temporal and spectral Landsat images were used as an input and processed using TerrSet, ERDAS imagine 2015, and ArcGIS 10.8.1 softwares. The Cellular Automata-Markov Chain model was used to predict the future urban and peri-urban areas. Pearson correlation coefficient was applied to examine the association among the population, urban, peri-urban growth, and its impact on arable land in Stata/SE v14. The findings revealed that urban and peri-urban lands increased by 7.5 km² (22.1%) and 1.0 km² (2.9%), while arable land decreased by –0.1 km² (–0.2%) from 1976 to 2019. It is also predicted to increase by 1.0 km² (2.80%) and 0.9 km² (2.70%) until 2029, while arable land is anticipated to shrink by –1.0 km² (–3.0%). The relationship among population growth, urban, and peri-urban land shows positive ($r=0.942$, $p=0.058$; $r=0.985$, $p=0.016$). However, arable land has been negatively correlated with population growth, urban, and peri-urban lands ($r=-0.610$, $p=0.392$). The result of this research is indispensable for urban planners and decision makers to optimize urban and peri-urban expansion related information without jeopardizing the size of arable lands.

Article Highlights

- (1) When population growth increases at a certain number, then the extent of urban/peri-urban areas tends to increase.
- (2) The spatial extent of urban and peri-urban areas have increased at the expense of arable land.

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- (3) The effects of urban/peri-urban areas growth can be declined through an integrated urban land use planning system.

Keywords Urban/Peri-Urban Land Expansion · Arable Land Loss · Remote Sensing · GIS · Shire Indaselassie City · North Western Tigray

1 Introduction

Both urban and peri-urban areas have been growing rapidly in different parts of the globe due to population increase and other factors, e.g., economic development. Studies indicated that more than half of the world's population resides in urban areas; however, this figure is anticipated to rise by 1.86 billion from 2009 to 2050 [1]. As a result, the extent of urban areas is predicted to increase by 50–69%. Most of the time, people move from villages to towns and cities seek a better life and economic opportunities in urban and peri-urban areas [2]. However, uncontrolled population growth and high migration flow from rural-to-urban areas aggravate the extent of urban and peri-urban expansion. This complicates the detection, and mapping of urban and peri-urban areas in arid and semi-arid environments for a long time [3]. Besides, the shifting of rural areas to urban or peri-urban class increases the number of inhabitants. As a result, it causes limited availability and loss of fertile arable land that can feed thousands of smallholder farmers and it alters the natural land cover into other uses, e.g., settlements due to anthropogenic factors [1, 4–6]. About 90% of the existing urban expansion has been focused on developing countries [7]. This may escalate the incidence of urban heat islands, air pollution, decline the soil and water quality, and potentially arable land for cultivation. Besides, it significantly influences climate because urban/peri-urban areas have emitted relatively higher surface and air temperatures in contrast with rural areas [8]. A significant reduction of arable land has been estimated in Southeast Asia by more than 10%; Western Asia and North Africa by up to 10%; South and Central Asia by 8%; and East Asia by up to 7% by 2050 [9]. The impacts of urban/peri-urban areas expansion of arable land would be unavoidable due to economic development and population growth [10]. However, China, Japan, and the United States of America have preserved their potential arable land from being altered to other land use types [10, 11]. The major challenges of farmers in most developing countries have great concerns about the negative impacts of urban expansion, e.g., human–animal health, access to clean water, abandonment of arable land, loss of grazing lands, and other important land cover types [12]. Urbanization has been recognized as a major factor that influences the change of arable and other land uses.

The situation is worsening in Sub-Saharan African countries (e.g., Ethiopia) because they have no effective urban land use planning and lack of community participation and integration, during planning and implementation processes [7, 9].

Ethiopia is one of the least urbanized countries in Africa [13]. However, the growth of urban areas has been widely perceived by its negative effects because smallholder farmers are losing their fertile arable land and are exposed to food insecurity. Therefore, urban, peri-urban, industrial, and infrastructure development has increased pressure on arable land [14]. This study has adopted a standardized definition for urban, peri-urban, and arable land. Urban land was defined as a city that comprises residential, commercial, and industrial complexes, including road surface and other infrastructure linked with built-up environment. Similarly, urban land refers to a complex of impervious surfaces [15]. A peri-urban land was also defined as the outer area of a city, rather than the business center in the middle, and it comprises a built-up area in the peri-urbanized area. The arable land was also defined as farmland used for growing crops and fruit trees at least once a year. The encroachments of urban, and peri-urban areas have been affected potential arable land because, most of the time, the arable land has been shifting to built-up functions (e.g., commercial, residential, industrial) due to high demand and population growth. Besides, the administrators of medium and small-sized cities have considered that the expansions of urban and peri-urban areas are more cost-effective than using the land for agricultural purpose. However, this perception is inaccurate, and the integration of agricultural sectors and urban economies are more important to link each other to exchange goods and services such as organic food and other raw materials. Similarly, the expansion of urban and peri-urban areas may help to own advanced technologies (e.g., machinery to improve farming system), infrastructure (e.g., road, electricity, telecommunication, health sectors, education, and access to clean water) [16]. It can also help strengthen rural and urban inhabitants' social and cultural integration.

Another essential reason for shrinking arable land was the lack of strong integration and cooperation with relevant stakeholders. The involvement of stakeholders in any developmental activities is paramount to diminish

competing interests and the negative impacts of urban and peri-urban expansion. For instance, the spatial extent of built-up areas in Mekelle City, northern Ethiopia, has increased by 3000 hectares from 1984 to 2014, and nearly 88% of the expansion were arable land [7]. As a result, the livelihood of farmers and the production and productivity of the area were affected from time-to-time. The unplanned urban and peri-urban encroachment have influenced natural resources and led to the use of arable land for non-agricultural activities [4, 9]. It is essential to give due focus to ensure social, economic, environmental, or natural resources sustainability. There is a need to assess the impact of rapid urban expansion [8]. For instance, A study on the dynamics of urban expansion using remote sensing and spatial metrics was carried out in Mekelle City of northern Ethiopia [7]; Agricultural land use change and its drivers was studied in Tulkarm City, northwestern of the West Bank of Palestine [9]; The loss of potential agricultural land and other cover types due to urban expansion were also investigated in Greater Cairo, Egypt [17, 18]. The growth of urban lands using remote sensing and GIS techniques was researched in Al Gharbiya-Middle Nile of Delta, Egypt [19]. All of the authors have reported that the expansion of urban lands have declined the productive arable land. The impact of urban expansion on surface temperature was also assessed in the Zhujiang Delta, China [8]. This author has reported that urban areas exhibit higher surface temperature and a significant amount of arable land reduction due to their conversion into urban and related land uses each year.

The study area is one of the rapidly growing and expanding medium-sized economic center cities in Tigray due to its topographic suitability for business, investment, access to a labor force, access to transportation, rapid population and economic development. As a result, there is high population density, high migration inflow and relatively better job opportunities for small and mid-carrier professionals. However, the rapid urban and peri-urban expansion of the study area causes a loss of arable land. Therefore, it is essential to assess and analyze the trends of urban and peri-urban lands expansion for better decision making in urban land use [15]. Yet, there has been no scientific research supported with geospatial technologies in the study area, but the local municipality has been used the conventional ways of assessment due to lack of knowledge/skill and experience in the application of geospatial technology for urban land use monitoring and modeling in general and impacts of urbanization on arable land in particular. Lack of comprehensive and up-to-date aerial images at moderate and high resolutions is also another challenge of the municipality. In addition, most of the previous studies conducted in different parts of the country did not include future urban/peri-urban growth,

and the statistical association among population growth, urban/peri-urban expansion, and arable land. As a result, it becomes a researchable topic by many researchers [1] and is considered a main research gap. This study is therefore carried out to fill the critical gaps observed in several studies in general and the study area in particular to contribute a better approach to urban and peri-urban area growth detection, monitoring and its impact analysis on arable land using Remote Sensing (RS) and Geographical Information System (GIS) and statistical models (e.g., Pearson correlation coefficient). Currently, most urban and peri-urban growth studies have been addressing the historical trends of urban growth. However, this study added future trends as well for better urban land use planning. We Ethiopians have also failed to have an integrated urban land use planning policy at national and regional levels. As a result, poor management of urban land use expansion has been causing an impact on fertile arable lands. Therefore, our study provides comprehensive information to urban land use planners and administrators. All this activity makes new research conducted in the study area. Nowadays, remote sensing and GIS have been effective, reliable, flexible and powerful technologies to provide comprehensive and more accurate information about existing and future spatial characteristics of urban and peri-urban growth, which is highly essential to enrich the present urban land use planning policy as well as land administration systems in the study area. Besides, multi-temporal and multi-spectral Landsat images at moderate spatial resolution (15 m \times 15 m after enhancement) were used in the study area. This indicated that the roles of remotely sensed data together with geospatial monitoring and modeling system technologies have been tremendously increasing. This study aimed to analyze the spatio-temporal patterns of urban, peri-urban expansion, and its impact on arable land in Shire Indaselassie, North Western Tigray. Besides, we also analyzed the association among the population, urban, peri-urban growth, and arable land of the study area. This paper is therefore important to provide timely and accurate geo-information findings for medium sized urban land use planners and decision makers.

2 Materials and methods

2.1 Study area

Shire Indaselassie is a medium-sized city located in the North Western zone of Tigray with a geographical extent between 38° 15' 0" to 38° 21' 0" E and 14° 4' 30" to 14° 7' 30" N (Fig. 1). The total area coverage is about 33.95 km². It consists of five major villages (*kebelles*) and four additional sub-villages (*Tabias*) (Fig. 1). The topography of the area is

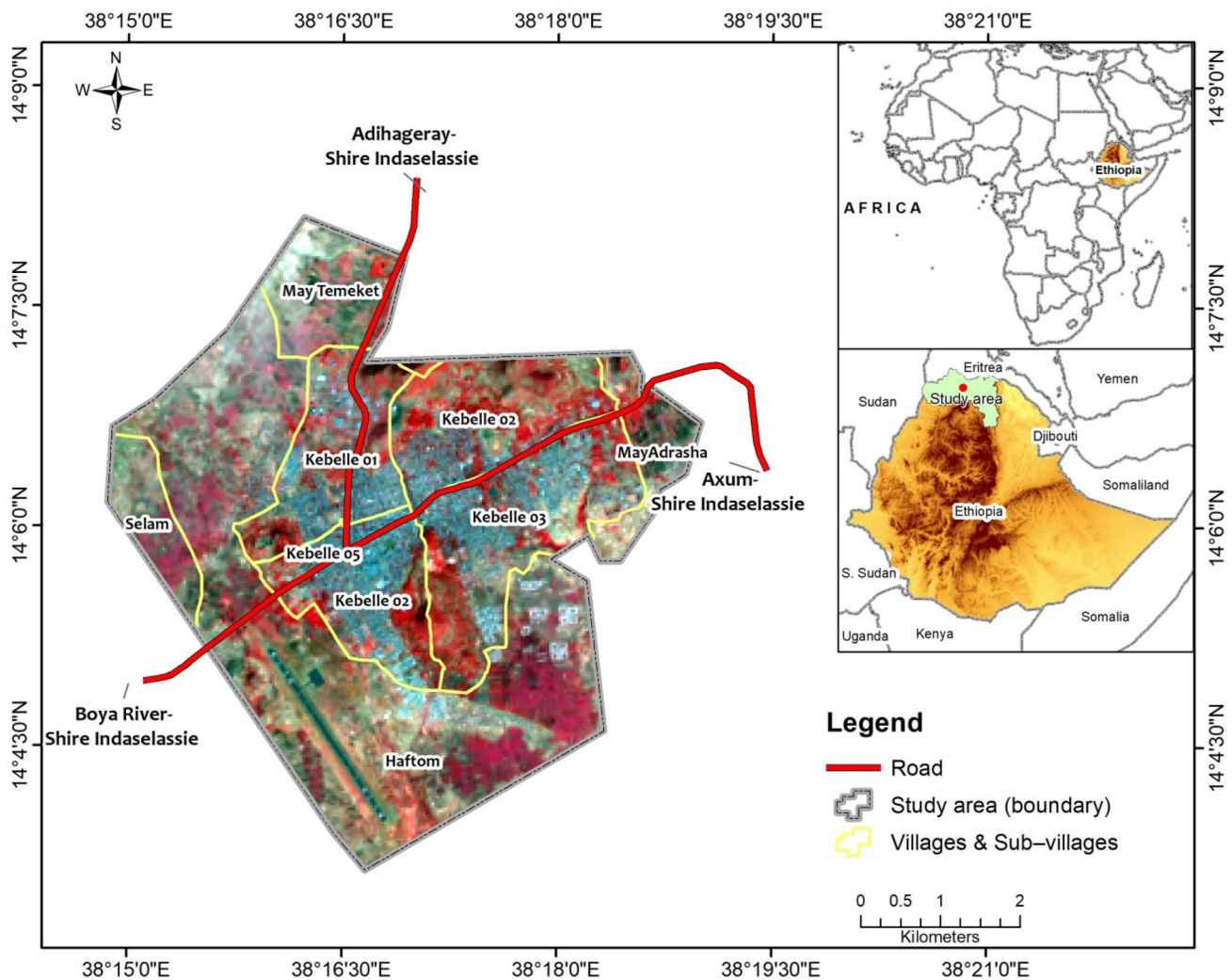


Fig. 1 Location of the study area

largely plain, ranging from 1802 to 2122 m above sea level (m.a.s.l) at the peaks of *Emba Koyessa* and *Emba Tseneat*. The study area receives up to 905 mm of annual rainfall and is characterized by unimodal patterns. The annual average temperature is also about 20.7 °C. After processing the Normalized Difference Vegetation Index (NDVI), the highest and lowest vegetation cover ranged between 0.64 and 0.136, respectively. The study area also comprised three major geological types such as Enticho sandstone, which covers 10.08 km² (29.70%), tectonic granite 23.34 km² (68.76%), and Tsaliat group 0.53 metamorphic rock km² (1.56%). In addition, chromic cambisols that covers 25.6 km² (75.3%), chromic vertisols 7.5 km² (22.1%), and eutric cambisols 0.9 km² (2.6%) are the different soil types of the study area. The total estimated population of the study area in the year 2022 was about 91,508, with a density of 2695 persons per km². This shows that the study

area is highly populated and largely depend on mixed agriculture.

2.2 Data collection

Remote sensing data is essential for monitoring urban and peri-urban expansion because of its repetitive coverage and real time data acquisition [19]. In this study, cloud free Landsat imageries of Multi-Spectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI) with path 182 & 169 and row 50 World Reference System (WRS-2) have been collected during the dry season from the United States Geological Survey (USGS) Landsat archives <http://earthexplorer.usgs.gov/> (Table 1). Besides, a total of 270-ground truth data sets (i.e., 30 training samples from each land cover type) was collected from the study area using an etrex 12 channel handheld Global Positioning

Table 1 Multi-temporal and spectral details of Landsat images used in the study

| Sensor | Band | Spectral (μm) | Date of image acquisition | Spatial (m) | |
|---|--|-------------------------------------|---|-------------------|----|
| Landsat 4–5 Multispectral Scanner (MSS) | Band 1—Green | 0.5–0.6 | January 08, 1976 | 60 | |
| | Band 2—Red | 0.6–0.7 | | | |
| | Band 3—Near Infrared (NIR) | 0.7–0.8 | | | |
| | Band 4—Near Infrared (NIR) | 0.8–1.1 | | | |
| Landsat 4–5 Thematic Mapper (TM) & Enhanced Thematic Mapper Plus (ETM+) | Band 1—Blue | 0.45–0.52 | December 30, 1986 December 09, 1996 June 04, 2009 | 30 | |
| | Band 2—Green | 0.52–0.60 | | | |
| | Band 3—Red | 0.63–0.69 | | | |
| | Band 4—Near Infrared (NIR) | 0.76–0.90 | | | |
| | Band 5—Shortwave Infrared (SWIR) 1 | 1.55–1.75 | | | |
| | Band 6—Thermal | 10.40–12.50 | | 120*(30) | |
| | Band 7—Shortwave Infrared (SWIR) 2 | 2.08–2.35 | | 30 | |
| | Band 8—Panchromatic | 0.52–0.90 | | 15 | |
| | Landsat Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) | Band 1—Ultra Blue (coastal/aerosol) | 0.435–0.451 | December 25, 2019 | 30 |
| | | Band 2—Blue | 0.452–0.512 | | |
| | | Band 3—Green | 0.533–0.590 | | |
| Band 4—Red | | 0.636–0.673 | | | |
| Band 5—Near Infrared (NIR) | | 0.851–0.879 | | | |
| Band 6—Shortwave Infrared (SWIR) 1 | | 1.566–1.651 | | | |
| Band 7—Shortwave Infrared (SWIR) 2 | | 2.107–2.294 | | | |
| Band 8—Panchromatic | | 0.503–0.676 | 15 | | |
| Band 9—Cirrus | 1.363–1.384 | 30 | | | |
| Band 10—Thermal Infrared (TIRS) 1 | 10.60–11.19 | 100*(30) | | | |
| Band 11—Thermal Infrared (TIRS) 2 | 11.50–12.51 | | | | |

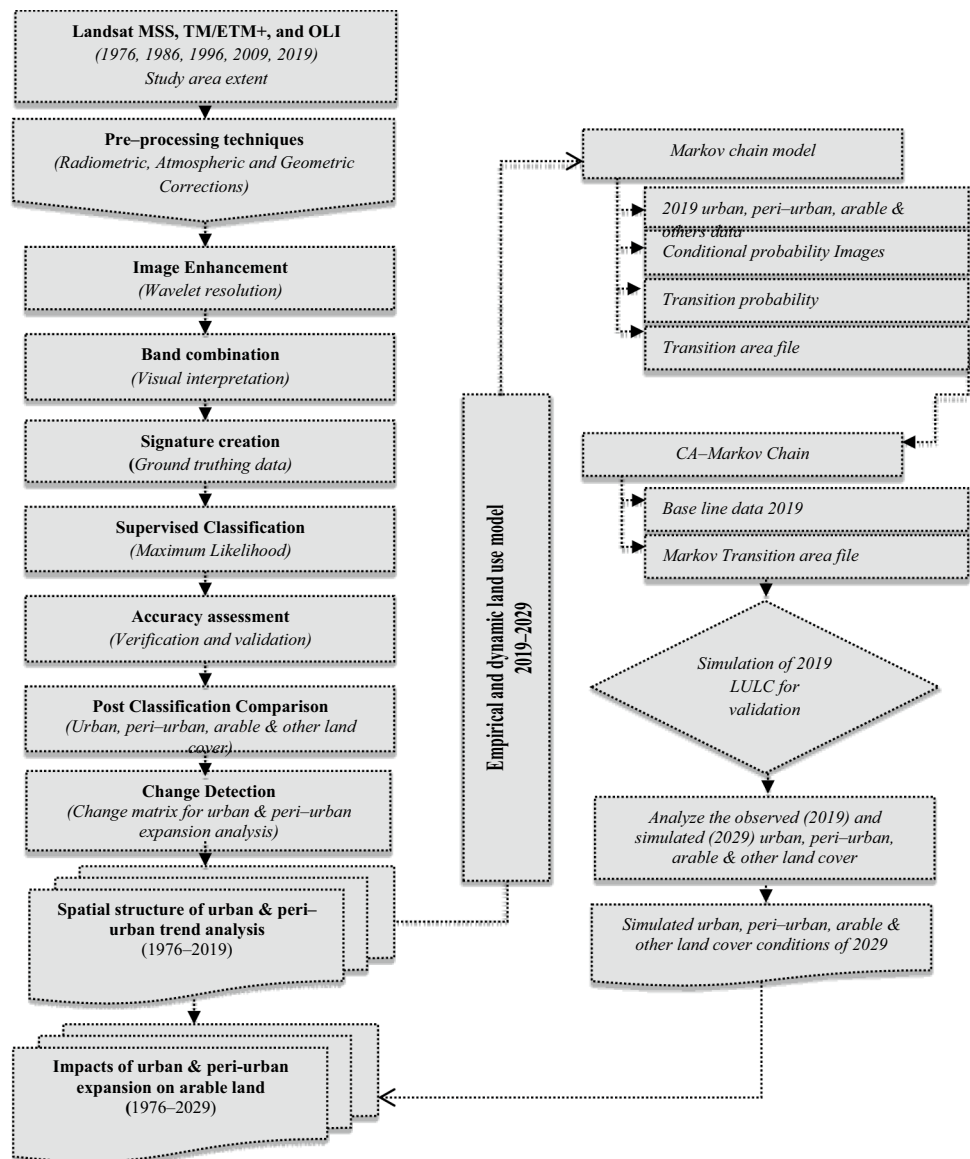
System (GPS) to improve the satellite image classification processes. In addition, ancillary data, such as an updated administrative map of the study area, were collected from the Tigray Statistical Agency.

2.3 Data processing and analysis

The digital image classification method supported with Geographical Information System (GIS) and maximum likelihood techniques was applied to analyze the expansion of urban and peri-urban areas. The image pre-processing techniques such as radiometric, atmospheric (e.g., Errors such as cloud, dark/haze, and noise) and geometric corrections (e.g., UTM Adindan Zone 37 local projection type) were applied to improve the qualities of all satellite imageries. Therefore, image pre-processing techniques are essential to correct, calibrate and remove errors. Besides, visual image interpretation was conducted by applying the false color composite (band combination techniques) for the TM and ETM+ products (4-3-2) i.e., near infrared-red-green and band 3-2-1- for MSS images and 5-4-3 (i.e., near infrared-red-green) for the OLI image. This helped us to interpret and apply the supervised image classification

technique using the Maximum Likelihood (ML) classifier algorithm in ERDAS Imagine v.2015 (Fig. 2). Furthermore, we analyzed the accuracy of all classified satellite imageries using the collected ground truth. About 135 ground truth data sets were used for image classification, and the remaining 135 were used for accuracy assessment. Predicting the future built-up area demand is important to assess the dynamics of urban/peri-urban lands and reduce the impacts [7]. However, accurate prediction is challenging because of the complexity of related socioeconomic factors. Linear regression model can be used to project the future built-up area demand [20]. However, this study employed a robust empirical and dynamic land use model (i.e., cellular automata and Markov chain (CA-Markov chain) model to estimate the future urban /peri-urban growth of the study area based on its historical trends. The CA-Markov chain model is more robust in predicting the future land use/cover change than others such as a Grid-based model (GeoMOD), Agent-based model (ABM), and Conversion of Land Use and its Effects at small scale modeling framework (CLUE or CLUE-S model). Because the CA-Markov chain model can simulate complex patterns of multiple land use/ covers types both spatially

Fig. 2 Impact of urban and peri-urban growth analysis on arable land (adapted from [21, 23])



and temporally. The model also has three major processes, namely; Cellular Automata, Markov chain, and validation. This advantage makes the model more robust than others. The TerrSet geospatial monitoring and modeling system, ERDAS imagine 2015, and ArcGIS v.10.8 software were used to analyze all satellite images. We also assessed population density by dividing the total population by the total land mass of the study area. The quantitative analysis of urban, peri-urban growth, arable and other cover types was calculated based on [21, 22] mathematical expression (Eq. 1–3):

$$C = (Fa - Ia) \tag{1}$$

$$C = (Fa - Ia) / Ia \times 100 \tag{2}$$

$$C = (Fa - Ia) / Ia \times \frac{1}{Y} \times 100 \tag{3}$$

where: C = annual rate of alteration in Urban, Peri-urban, Arable and other cover types, Fa and Ia = final and initial area coverage in km^2 , and Y = time span between the initial and final period.

Furthermore, this research tested the association among the population, urban, peri-urban growth and its impact on arable land using the Pearson statistical correlation coefficient in Stata/SE v14 as follows (Eq. 4).

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}} \tag{4}$$

where r = Pearson Correlation Coefficient, n = number of pairs, $\sum xy$ = sum of x and y values, $(\sum x) = \text{sum of } x \text{ values}$, $(\sum y) = \text{sum of } y \text{ values}$, $\sum x^2 = \text{sum of the squared } x \text{ value}$, $\sum y^2 = \text{sum of the squared } y \text{ value}$.

3 Results and discussions

3.1 Analysis of the spatial–temporal urban, peri-urban, arable and other land cover patterns

This study identified the spatial distribution and areal extent of nine major land use types. However, due to the scope of the study, focus was given to urban, peri-urban, and arable land change from the period 1976 to 2019 (Fig. 3 and Table 2). The overall accuracy and kappa coefficient of the findings for the period 1976, 1986, 1999, 2009, and 2019 was 85.8%, 86.25%, 88.25%, 91.0% and 93% with an excellent agreement kappa coefficient of 0.80, 0.81, 0.83, 0.85, and 0.86, respectively (see the attached supplementary material appendix 1 for details). This study found that the expansion of urban and peri-urban lands have occurred at different spatial

and temporal scales during the last four decades (Fig. 3 and Table 2). For instance, in the period 1976, AL was the dominant land cover type 14.2 km² (41.4%) of the study area, followed by GL 9.5 km² (28.4%), DBL 7.2 km² (21.1%), DeBL 1.6 km² (4.8%), UBA 0.4 km² (1.2%) and CF 0.1 km² (0.3%) respectively. In the final period of 2019, the spatial coverage of most LULC types was completely changed into other cover types. The AL was 14.1 km² (41.8%), remains the dominant cover type, followed by UBA 7.9 km² (23%), DBL 5.2 km² (15.5%), GL 2.2 km² (6.7%), SuBA 1.8 km² (5.3%), DeBL 0.9 km² (2.8%), PFL 0.7 km² (2.1%), CF 0.5 km² (1.6%), and finally by AP 0.5 km² (1.3%) (Table 2) in the same period. This study reported that the urban and peri-urban lands increased by 7.5 km² (22.1%) and 1.0 km² (2.9%) from the period 1976–2019, but the arable land decreased by –0.1 km² (–0.2%). It is also predicted that an increase in urban and peri-urban lands by 1.0 km² (2.80%) and 0.9 km² (2.70%) from the period 2019 to 2029 at an annual growth rate of 0.1 km² and 0.09 km², respectively. On the other hand, the arable land, which is the backbone of the study area, is anticipated to shrink by –1.0 km² (–3.0%) at an annual rate of –0.1 km². A loss of 9,600 ha from agricultural land between 2010 and 2018 observed in greater

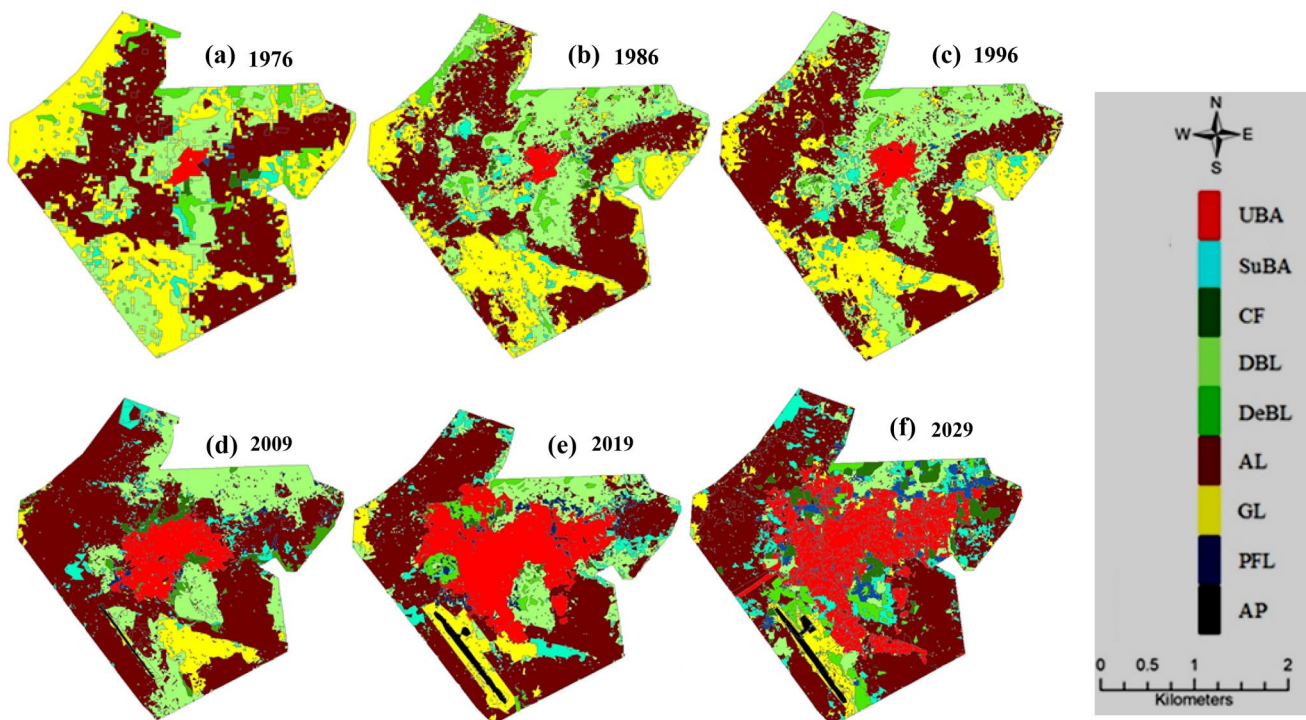


Fig. 3 Spatial–temporal patterns of urban, peri-urban, and other land cover types from 1976 to 2029. UBA Urban area, SuBA Peri-urban area, CF Church forest, DBL Degraded bush & shrub lands,

DeBL Dense bush & shrub lands, AL Arable land, GL Grass land, PFL Plantation forest, AP Airport

Table 2 Temporal trends of urban, peri-urban, arable and other land cover types of the study area from 1976–2029

| LC | Rate of Change | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------------------|-----------------|-------|-----------------|-------|-----------------|-------|-----------------|-------|-----------------|-------|-----------------|-------|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| | Years | | 1976–1986 | | 1986–1996 | | 1996–2009 | | 2009–2019 | | 2019–2029 | | 1976–2029 | | | | | | | | | | | | | | |
| | km ² | % | km ² | % | km ² | % | km ² | % | km ² | % | km ² | % | km ² | % | | | | | | | | | | | | | |
| UBA | 0.4 | 1.2 | 0.5 | 1.5 | 0.9 | 2.6 | 3.1 | 9.1 | 7.9 | 23.0 | 8.9 | 25.8 | 0.1 | 0.4 | 1.1 | 2.2 | 6.5 | 4.8 | 14.1 | 1.0 | 2.8 | 7.5 | 22.1 | 8.5 | 25.0 | | |
| SuBA | 0.8 | 2.6 | 1.2 | 3.4 | 1.3 | 3.7 | 1.5 | 4.5 | 1.8 | 5.3 | 2.8 | 8.0 | 0.4 | 1.0 | 0.2 | 0.3 | 0.8 | 0.3 | 0.8 | 0.9 | 2.7 | 1.0 | 2.9 | 1.9 | 5.7 | | |
| AL | 14.2 | 41.4 | 13.4 | 39.1 | 14.7 | 43.2 | 17.6 | 52.1 | 14.2 | 41.8 | 13.2 | 38.4 | -0.8 | -2.4 | 1.3 | 3.9 | 2.9 | 8.4 | -3.4 | -10.1 | -0.9 | -2.8 | -0.1 | -0.2 | -1.0 | -3.0 | |
| Other cover types | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CF | 0.1 | 0.3 | 0.1 | 0.1 | 0.0 | 0.1 | 0.5 | 1.8 | 0.5 | 1.6 | 1.8 | 5.3 | 0.0 | -0.1 | 0.0 | -0.1 | 0.4 | 1.3 | 0.1 | 0.2 | 1.3 | 3.8 | 0.4 | 1.3 | 1.7 | 5.0 | |
| DBL | 7.2 | 21.1 | 9.5 | 29.0 | 9.6 | 28.3 | 8.0 | 23.4 | 5.2 | 15.5 | 2.2 | 6.5 | 2.3 | 6.8 | 0.1 | 0.3 | -1.6 | -4.7 | -2.8 | -8.3 | -3.0 | -8.8 | -2.0 | -5.8 | -5.0 | -14.7 | |
| DeBL | 1.6 | 4.8 | 1.7 | 4.9 | 0.8 | 2.4 | 0.8 | 2.3 | 0.9 | 2.8 | 1.7 | 4.9 | 0.0 | 0.1 | -0.9 | -2.6 | 0.0 | 0.1 | 0.1 | 0.3 | 0.7 | 2.2 | -0.7 | -2.1 | 0.0 | 0.1 | |
| GL | 9.5 | 28.4 | 7.5 | 21.8 | 6.5 | 19.5 | 1.8 | 5.3 | 2.2 | 6.7 | 1.7 | 4.9 | -2.0 | -5.9 | -1.0 | -2.9 | -4.7 | -13.8 | 0.4 | 1.0 | -0.5 | -1.5 | -7.3 | -21.6 | -7.8 | -23.1 | |
| PFL | 0.0 | 0.2 | 0.1 | 0.2 | 0.1 | 0.2 | 0.4 | 1.2 | 0.8 | 2.1 | 1.2 | 3.6 | 0.0 | 0.0 | 0.0 | 0.4 | 1.0 | 0.3 | 1.0 | 0.3 | 1.0 | 0.5 | 1.5 | 0.7 | 2.1 | 1.2 | 3.5 |
| AP | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.4 | 0.5 | 1.3 | 0.5 | 1.5 | 0.0 | 0.0 | 0.0 | 0.1 | 0.4 | 0.3 | 1.0 | 0.3 | 1.0 | 0.0 | 0.1 | 0.5 | 1.3 | 0.5 | 1.5 |
| Total | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | 33.95 | 100.0 | |

UBA Urban area, SuBA Peri-urban area, CF Church forest, DBL Degraded bush & shrub lands, DeBL Dense bush & shrub lands, AL Arable land, GL Grass land, PFL Plantation forest, AP Air port

Cairo [17]. The authors have also reported that most of the urban expansion has occurred in agricultural land. Besides, the authors have clearly indicated that not only the agricultural land being lost due to urban/per-urban expansion, but it also becomes fragmented, unproductive, and vulnerable to be affected by the advancement of urban areas. This is highly corroborated by our findings. An increased trend of urban areas was observed by 47.68%, while the potential cropland has declined by 48.37% in the Zhujiang Delta, China [8]. The need for land for urban settlement from different land cover types is unavoidable. The existence of political stability and better economic development observed in the past 30 years in Tigray region, Shire Indaselassie city demands large urban land for housing and other urban function developments. Since the establishment of the city, the expansion of the built-up area of the Shire Indaselassie city extends towards East, South and West direction due to the flat nature of the landscape while in the north is hindered by a chain of mountainous landscape called *Addi Anteltila, Koyetsa, Giorgis Lekamba, and Afincha Dimu*.

Identifying such urban growth is important for urban planners and land administrators to characterize and analyze the urban expansion of the Shire Indaselassie city. The quantitative output of such urban growth is also important for decision makers to properly administer and manage the wise use of urban land for different urban functions. Studies have also indicated that urban areas have been extended at the expense of arable, barren, and to some extent, grass or grazing lands. A study conducted by [7] in Mekelle city, northern Ethiopia and [24] in the Qiantang River watershed in China clearly shows that the rapid urban expansion took place primarily at the expense of agricultural land in the urban fringe. The higher rate of urban areas encroaching in the study area tends to the loss of potential arable and grassland, which is important for maximizing crop and animal production. Therefore, spatial planning may support to normalize the demand of urban/peri-urban expansion. Lack of integrated urban planning has been considered as one of the most important factors for shrinking arable land in Tulkarm [9]. Similarly, the municipality of the Shire Indaselassie city has allocated and expanded its built-up area mainly towards the east direction in the potential. Suitable arable land found in the *May Adrasha* village to the south and west direction in Haftom village of the suburb area. Moreover, this study corroborated with the aforementioned factors because it is a major problem in the city of Shire Indaselassie, North Western Tigray. In addition, the medium sized urban/peri-urban areas have expanded quickly than large and small sized cities.

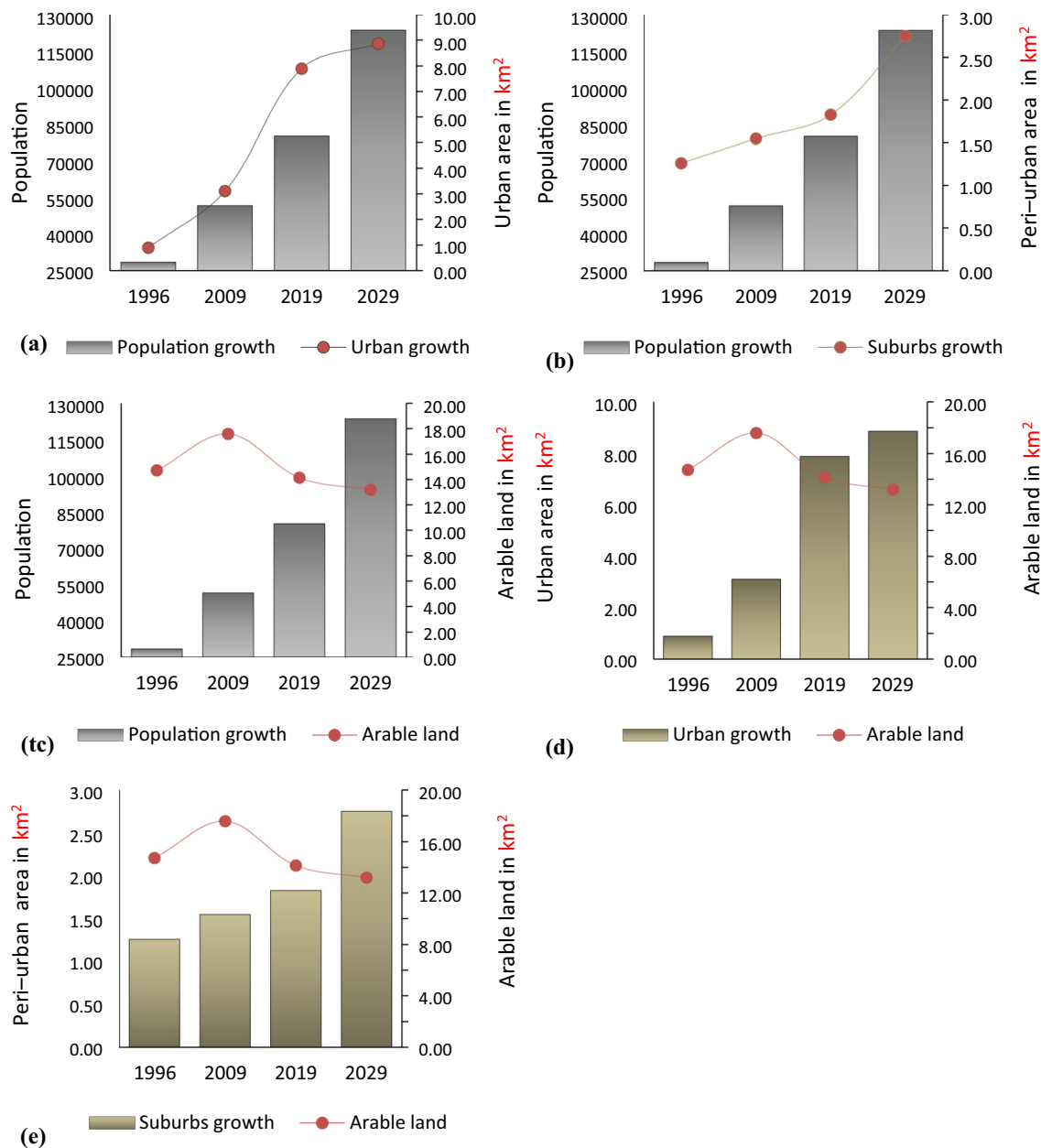


Fig. 4 Trends of population, urban, peri-urban and arable land

3.2 Impact of population, urban, and peri-urban growth on arable land

The proportion of population growth and urban area expansion at Shire Indaselassie city is a measure of quantifying built-up area expansion. The findings indicated that there have been positive trends in population, urban, and peri-urban, while arable land has not been growing proportionally during the study period (Fig. 4). In the study area, most of the smallholder farmers have been engaging themselves in farm activities to feed their family. However, the collective effects of

population, urban, and peri-urban expansions have influenced their potential arable land. Therefore, the increase of population growth has been accompanied by the expansion of urban and peri-urban. In study area, population of the city is expected to grow from 28,494 in 1996 to 123,574 in the year 2029 and the trends of population growth result remain similar throughout the study years (Fig. 4a-c). In the base year (1996), the area of urban growth in the city was 0.9 km² and gently grew to 3.22 km² in 2009 while abruptly to increase to 8.86 km² in 2029 (Fig. 4a). The spatial coverage of the peri-urban area was 1.26 km² in the year 1996; however, it is

predicted to gently grow to 2.75 km² in 2029 (Fig. 4b). Slight increase has also been observed in arable land from 14.72 to 17.57 km² during the period 1996 and 2009. However, it has been declined to 14.14 km² in 2019. It is also predicted to decline into 13.19 km² in the year 2029 due to the existing trends of population increment (Fig. 4c). Urban land grew from 0.9 km² in 1996 to 7.89 km² in 2019. It is also anticipated to grow by 8.86 km² in the year 2029 (Fig. 4d). Peri-urban area has been slightly grown from 1.26 km² in the year 1996 to 1.83 km² in the year 2019, but it is expected to grow by 2.75 km² in the year 2029 (Fig. 4e).

This study also found a mean population density of 2091 per km² which is high in comparison to other medium-sized cities of Tigray, such as Aksum and Alamata. For instance, in the study area, both urban and peri-urban lands increased for the period 1976–2019 by 7.5 km² (22.1%) and 1.0 km² (2.9%), but the arable land decreased by – 0.1 km² (– 0.2%). This study has also predicted an increase from the period 2019 to 2029 in urban and peri-urban lands by 1.0 km² (2.80%) and 0.9 km² (2.70%) at an annual growth rate of 0.1 km² and 0.09 km², respectively. On the other hand, the arable land is anticipated to shrink by – 0.9 km² (– 2.8%) an annual rate of – 0.1 km². Similarly,

Tuyen (2013) found a loss of 0.5 million hectares due to urban expansion processes in Vietnam between 1993 and 2008. However, this study reported that the arable land will be diminished by – 0.95 km² (– 2.79%) at a rate of –0.09 km² until the same period. Similarly, a conversion of 0.7 million hectares arable land into built-up area between 1987 and 2000 were observed in the Beijing–Tianjin–Hebei region [5]. Urban expansion occurs at the expense of the most fertile soils in Al Gharbiya, Middle Nile of Delta in Egypt [19]. This study highlighted that the direct loss of arable land due to urban and peri-urban expansion causes a considerable impact on the production and productivity of livestock and crop. For instance, it decreases food grain production, destroying natural resources or losing vegetation cover, and wildlife habitats (biodiversity). Furthermore, it may escalate the incidence of environmental pollution in the area. Therefore, it is recommended to carry out reforms of the existing urban land use planning based on the land capability and suitability. This can help to diminish the impacts of urban and peri-urban expansion on fertile and productive arable land. It is also suggested to conduct further studies on the socioeconomic impacts of urban and peri-urban expansion.

Table 3 Transitional probability matrix of urban/peri-urban, arable land, and other cover types of the study area from the period 2009–2029

| 2009–2019 | UBA | SuBA | AL | CF | DBL | DeBL | GL | PFL | AP |
|------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| UBA | 0.243 | 0.217 | 0.343 | 0.007 | 0.036 | 0.003 | 0.123 | 0.006 | 0.022 |
| SuBA | 0.015 | 0.256 | 0.094 | 0.022 | 0.234 | 0.018 | 0.343 | 0.017 | 0.002 |
| AL | 0.034 | 0.062 | 0.703 | 0.017 | 0.068 | 0.016 | 0.081 | 0.013 | 0.006 |
| Other cover type | | | | | | | | | |
| CF | 0.031 | 0.060 | 0.133 | 0.153 | 0.193 | 0.205 | 0.110 | 0.108 | 0.007 |
| DBL | 0.019 | 0.168 | 0.075 | 0.125 | 0.249 | 0.087 | 0.123 | 0.153 | 0.001 |
| DeBL | 0.016 | 0.119 | 0.047 | 0.199 | 0.137 | 0.268 | 0.059 | 0.152 | 0.002 |
| GL | 0.020 | 0.118 | 0.234 | 0.061 | 0.249 | 0.045 | 0.216 | 0.054 | 0.004 |
| PFL | 0.016 | 0.041 | 0.103 | 0.136 | 0.434 | 0.176 | 0.027 | 0.067 | 0.001 |
| AP | 0.033 | 0.166 | 0.163 | 0.006 | 0.062 | 0.001 | 0.539 | 0.013 | 0.017 |
| UBA | 0.427 | 0.193 | 0.089 | 0.000 | 0.000 | 0.000 | 0.074 | 0.000 | 0.218 |
| 2019–2029 | | | | | | | | | |
| SuBA | 0.041 | 0.274 | 0.009 | 0.001 | 0.100 | 0.003 | 0.301 | 0.002 | 0.269 |
| AL | 0.002 | 0.028 | 0.964 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.003 |
| CF | 0.030 | 0.015 | 0.026 | 0.367 | 0.026 | 0.431 | 0.000 | 0.098 | 0.007 |
| Other cover type | | | | | | | | | |
| DBL | 0.010 | 0.226 | 0.060 | 0.194 | 0.400 | 0.031 | 0.001 | 0.079 | 0.000 |
| DeBL | 0.001 | 0.023 | 0.006 | 0.112 | 0.000 | 0.830 | 0.000 | 0.028 | 0.000 |
| GL | 0.001 | 0.078 | 0.331 | 0.012 | 0.111 | 0.010 | 0.217 | 0.030 | 0.210 |
| PFL | 0.024 | 0.132 | 0.018 | 0.437 | 0.172 | 0.144 | 0.000 | 0.073 | 0.000 |
| AP | 0.043 | 0.030 | 0.097 | 0.000 | 0.000 | 0.000 | 0.391 | 0.000 | 0.440 |

UBA Urban area, SuBA Peri-urban area, CF Church forest, DBL Degraded bush & shrub lands, DeBL Dense bush & shrub lands, AL Arable land, GL Grass land, PFL Plantation forest, AP Air port

3.3 Transitional probability matrix for predicting the 2029 urban and peri-urban growth and model verification

The probability of changing one land use class into another land use class can be determined by the transition probability matrix using the markov chain model. Markov chain model is one of the reasonably performing models when conducting the urban land use change research and many scholars such as [21, 25, 26] have applied for predicting the future expansion of built-up and other land cover types. The sum of all values in each horizontal rows of the transition matrix ranges between the values of zero and one (Table 3). This indicates that the probability of changing one type of land cover class into another one. Table 3 shows the transition probability matrix for predicting the 2029 urban, peri-urban, arable and other lands based on the 2009–2019 transitional probability matrix. This transitional probability matrix helps to comprehend the probabilities of urban, peri-urban, arable and other land alteration and control its spatial distribution from its earlier coverage [23]. The probability of SuBA to UBA alteration is 0.041, AL to UBA 0.002, and AL to SuBA 0.028 (Table 3). This study has determined that the probability of AL alteration

to SuBA is higher than AL to UBA because most of the time the AL is directly shifting into a built-up area for residential and other purposes.

Furthermore, in the period from 2019 to 2029, UBA, SuBA, and GL will be highly changing to AP land cover class. This could be true with the current progressive growth of the city; the expansion of the existing airport may demand extensional land from the nearby land cover classes. Similarly, DeBL and PFL are supposed to be highly changed into CF. This could be because the two land cover classes are protected by the local community bylaws in the government rehabilitation programme. Moreover, the projected urban/peri-urban expansion and other crucial land cover classes of 2029 were validated after the agreement between the actual and simulated land cover classes of 2019 were analyzed and fulfilled the minimum level of agreement requirement (i.e., $\geq 85\%$). The results indicated that the Cellular Automata-Markov Chain model was agreed with 98.66% with the reference data (Table 4). The AL, DBL, DeBL, PFL and AP land cover classes of the study area were perfectly aligned with slight model overestimation errors. However, the UBA, SuBA, and CF were perfectly fitted with the actual land cover type by 96.2%, 87.78%, and 96.0%, respectively.

Table 4 Model validation and verification based on the actual and simulated urban and peri-urban growth and other land use types of 2019

| LC | Actual land use classes of 2019 | | Simulated land use classes of 2019 | | Area change between the actual & simulated (\pm) land use classes | | Level of agreement |
|----------------------------|---------------------------------|--------|------------------------------------|--------|---|------|--------------------|
| | km ² | % | km ² | % | km ² | % | |
| UBA | 7.90 | 23.27 | 7.6 | 22.39 | – 0.30 | 1.21 | 96.20 |
| SuBA | 1.80 | 5.30 | 1.58 | 4.65 | – 0.20 | 1.07 | 87.78 |
| AL | 14.15 | 41.68 | 14.7 | 43.30 | 0.55 | 0.02 | 103.89 |
| CF | 0.50 | 1.47 | 0.48 | 1.41 | – 0.00 | 0.08 | 96.00 |
| DBL | 5.20 | 15.32 | 5.4 | 15.91 | 0.20 | 0.00 | 103.85 |
| DeBL | 0.90 | 2.65 | 0.93 | 2.74 | 0.03 | 0.89 | 103.33 |
| GL | 2.20 | 6.48 | 1.9 | 5.60 | – 0.30 | 0.04 | 86.36 |
| PFL | 0.80 | 2.36 | 0.82 | 2.42 | 0.02 | 0.06 | 102.50 |
| AP | 0.50 | 1.47 | 0.54 | 1.59 | 0.04 | – | 108.00 |
| Total | 33.95 | 100.00 | 33.95 | 100.00 | – | – | – |
| Overall level of agreement | 98.66 | | | | | | |

Table 5 Pearson correlation coefficient among population growth, urban, peri-urban growth, and arable land

| | Total population | Urban area | Peri-urban area | Arable land |
|------------------|------------------|-----------------|-----------------|-------------|
| Total population | 1.000 | | | |
| Urban area | 0.942 (0.058)* | 1.000 | | |
| Peri-urban area | 0.985 (0.016)** | 0.869 (0.131) | 1.000 | |
| Arable land | – 0.610 (0.392) | – 0.610 (0.391) | – 0.610 (0.392) | 1.000 |

** and * are significant at 5 and 10%

3.4 Relationships among population, urban, peri-urban expansion, and arable land

Table 5 shows the Pearson correlation coefficient among population growth, urban, peri-urban expansion, and arable land in the study area. The results indicated that there is positive, very strong and statistically significant correlation between total population growth and urban expansion ($r = 0.942$, $p = 0.058$); total population growth and peri-urban expansion ($r = 0.985$, $p = 0.016$); Urban and peri-urban expansion ($r = 0.869$, $p = 0.131$). This means that when population growth increases at a certain number then the spatial extent of urban, peri-urban areas tends to increase at the expense of arable land. In addition, there is negative, strong but not statistically significant correlation between total population growth and arable land ($r = -0.610$, $p = 0.392$). Our findings were in agreement with [27, 28] that have reported the correlation between urban and agricultural land was negative. If the arable land diminished at alarming rate, then the issue of food insecurity or saturation could be critical due to population growth [19]. Therefore, understanding of the relationship between urban, peri-urban expansion and arable land loss is essential to preserve potential lands [29].

4 Conclusions

In this study, an integrated approach of remote sensing and GIS technology supported by the empirical and dynamic model was used to analyze the spatial-temporal patterns of urban, peri-urban growth and its impacts on arable land in Shire Indaselassie, North Western Tigray. The findings revealed that the arable land was converted into urban, peri-urban, and other land cover types in the last four decades. During the period 1976–2019, the urban and peri-urban lands were increased by 7.5 km² (22.1%) and 1.0 km² (2.9%), but the arable land decreased by –0.1 km² (–0.2%). This study has also predicted an increase in urban and peri-urban lands by 1.0 km² (2.80%) and 0.9 km² (2.70%) from 2019 to 2029 with an annual growth rate of 0.1 km² and 0.09 km², respectively. On the other hand, the arable land is anticipated to shrink by –0.9 km² (–2.8%) with an annual rate of –0.1 km². Moreover, this study found that the relationship between population growth and urban expansion is positive and strong ($r = 0.942$, $p = 0.058$); population growth and peri-urban expansion ($r = 0.985$, $p = 0.016$); Urban and peri-urban expansion ($r = 0.869$, $p = 0.131$). Arable land was negatively correlated with population growth, urban and peri-urban ($r = -0.610$, $p = 0.392$). The study area will expand towards

the East, South and West direction due to the flat nature of the landscape while the north direction is hindered by a chain of mountainous landscape called *Addi Anteltilla*, *Koyetsa*, *Giorgis Lekamba*, and *Afincha Dimu*. This study, therefore, suggested that there is a need to carry out reforms on urban land use planning based on land suitability to improve and preserve fertile arable land that can enhance the livelihood of smallholder farmers in the study area. In general, the rapid expansion of urban built-up area results in a remarkable and continuous reduction of arable land and when informal settlement flourish in an urban area it will accelerate the incidence of environmental pollutions, and destruction of natural resources that requires great attention by urban land use planners and policy makers.

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Declarations

Conflict of interests The authors have no relevant financial or non-financial interests to disclose.

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