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Spatiotemporal analysis of urban growth on forest and agricultural land using geospatial techniques and Shannon entropy method in the satellite town of Ethiopia, the western fringe of Addis Ababa city

Kiros Tsegay Deribew

Abstract

Rapid conversion of conserved land and cropland to non-agricultural purposes is threatening the ecological areas and dominant agricultural activities that are the main sources of livelihood in urban fringe areas of Addis Ababa City. The combinations of government policy, socioeconomic, demographic dynamics, and biophysical triggers have driven such transformation. However, the recent fast urban expansion and infrastructural development could have accelerated the severity and rate at which urban growth impacts the ecosystem and fertile agricultural land. Yet, little attention is given about their impacts on forest and farming communities in the western fringe areas of Addis Ababa during the recent past. This study, therefore, aimed at quantifying and analyzing the trends of the urban growth and its impacts on flora and agricultural land in Sebeta-Awas town using an integrated GIS tool, remote sensing technique, and Shannon entropy method. Landsat TM of 1986, ETM+ of 2002, and OLI of 2019 were used to produce land use/land cover (LULC) classes. Object-based classification technique was carried out to generate the LULC and to measure the changes in the urban land-use class within the satellite town in the year 1986, 2002, and 2019. Shannon entropy method was applied to model study area's urban sprawl, growth trend, and spatial change. Over the past three decades (1986–2019), Sebeta-Awas town has experienced severe urban sprawl following lack of proper development control and management. The annual urban growth rates of 1.2, 5.5, and ~15% for the periods of 1986, 2002, and 2019, respectively were obtained mainly at the expenses of agricultural land (25.48%) and forest land (16.6%), catalyzed urban sprawl which finally led to serious deforestation and reduction in rural farmland. The findings indicate that the average of entropy index increased from 0.02 in the year 1986 to 0.996 in the year 2019, indicating more dispersed urban growth to the outskirts, and spatially indicating anticlockwise shifting. In this regard, more than 90.2% of forest loss due to agricultural encroachment, built-up area expansion, and construction was widely observed in Sebeta and Alem Gena areas, of course, Northeast zone in this study. It is concluded that deforestation and continual evacuation of farming communities in the urban fringe areas (Continued on next page)

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due to rapid urban expansion in the name of investment and infrastructural development is expected to be worsened in the near future unless strong policy revision and management actions are undertaken.

Keywords: Concentric rings, Entropy index, Urbanization, Urban sprawl

Introduction

Urbanization is the rapid proportion of the population living in urban areas, and urban expansion is a further physical expansion (spatial extent) of already existing urban centers (Alig and Healy 1987; Cheng and Masser 2003; Wakode et al. 2014). The world has experienced rapid urbanization and slum proliferation in the twentieth-first century (Singh 2014; Kamusoko and Gamba 2015; Subasinghe et al. 2016; Liu et al. 2019). United Nation indicated that only 13% of the world population lived in urban areas in 1990. This has also been heightened to 30% by the mid of the 1990s. However, over the past two decades, the number of urban dwellers has already dramatically surpassed its peripheries counterparts. In this regard, the global population of the urban share would grow to 68% by 2050 (UN 2015). In the same projection, Africa and Asia are projected to account for nearly 90% of the world's urbanization rates in the coming three decades. Even though, there are considerable variations in urbanization rates and shares among less and more developed world, in the developing world (~4% a year) in general is urbanizing much faster than in developed countries (Soubotina 2004; Kiamba 2012). In the developed world, urbanization rates are constant or decline due to regular settlement patterns and relatively stable population growth. In contrast, developing countries are still industrializing and urbanizing, so attract even more population from rural areas where population growth rate is relatively higher (3% a year), and experiences null job opportunities. Hence, unlike the developed world where urbanization process is triggered by industrialization, the urbanization process in developing countries is characterized by demographic changes such as rapid natural population growth and rural-urban migration, which is, in turn, stimulated by urban growth. Despite its socio-economic significance, urbanization threatens biodiversity, and ecosystems, this has led to ecological depletion and ecosystem disruptions in the ecologically important areas (Liao et al. 2018; Wang et al. 2018; Deribew and Dalacho 2019).

Urbanization in Ethiopia is characterized by a low level of urbanization even by African standard, where only 18% of populations live in the urban area, of which 23% are living in metropolitan Addis Ababa (PCC 2008; CSA 2015). Yet, Addis Ababa has recorded a relatively high growth rate of urban population (4% annually); double that of rural areas. This was due to the high population growth rate (2.75%), accompanied by a high rate of

rural-urban and urban-urban migration (Lohnert 2017). Nevertheless, Teller and Assefa (2010) and Puertas and Henriquez (2014) state that a high growth rate and demographic shift are not often accompanied by a development in socioeconomic services and infrastructure, and economic and employment capacity of the urban centers to support the growing population.

Addis Ababa City is a nodal point perceived to create job opportunities and improve socio-economic activities in the country (Mohamed et al. 2019). Studies highlighted that the city has been rapidly expanding towards its peri-urban areas to accommodate the ever-increasing population, settlements, and infrastructural developments (Samson 2009; Leulseged et al. 2011). This rapid outward urban expansion due to the increasing urban population marked that peri-urban areas are growing much more quickly than the formal urban center. However, such unprecedented population growth coupled with colossal developmental activities in its undesirable forms in urban fringe has negative impacts on the ecosystem, natural resources, human health and has caused some socioeconomic problems (Mohamed et al. 2019). Such phenomena drive the land cover transformation pattern which proceeded to ecological deterioration, poverty, urban sprawl, informal settlements, urban informality, unstructured and unplanned development mainly in the fringe of the city (Abebe et al. 2019; Deribew and Dalacho 2019). The vicinities of Addis Ababa city have an exceptionally experienced intense level of landscape conversion mainly due to demographic pressure (rural-urban and urban-urban migration) attributed to a high rate of urban expansions and infrastructural developments (FZSeP 2011).

The influx of unemployed people looking for job opportunities due to massive investment in industries, infrastructural, and real estate developments in the urban fringes of Addis Ababa has brought drastic changes in the landscape. Studies revealed that in the central highlands of Ethiopia close to Addis Ababa have seen a rapid expansion of agricultural land at the expense of forest land over the last half-century (Minta et al. 2018; Deribew and Dalacho 2019). The former and latter studies reported that forest land declined by 73 and 50% of the total during 1957–2014 and 1957–2017 in Dendi-Jeldu mountains and North-east Addis Ababa city, respectively in the central highlands of Ethiopia. Though both authors reported a massive loss of forest cover to cultivated land, pastureland, and settlements, the rate at which farmland increase over time had declined mainly due to a shortage of available suitable land for cultivation. The

same pattern has also been observed in South Wollo, North-central Ethiopia (Rosell et al. 2017). However, the latter study showed that in terms of gains settlements/built-up areas obtained 7.7% of the total area, of which 7.2% obtained from both agricultural land and forests in the North-eastern fringe of Addis Ababa. The high rate of urban expansion and infrastructural developments due to shift of demographic pressure following the new master plan of Addis Ababa and outward migration of urban poor people to the eastern margin of the city in search of employment opportunities in real-estate developments, industries, and infrastructural developments were found to be the main drivers. Similarly, the 24 years report (1986–2010) conducted by Leulseged et al. (2011) showed that ~121 km² of landscape mainly forest and croplands were converted into built-up areas. This may have far-reaching impacts on the peri-urban ecosystem and livelihood economy.

Also, the recent expansion of residential, commercial, industrial areas, and infrastructural developments, accompanied by government investment policy was considered to be the major driver of landscape change (Deribew and Dalacho 2019). Yet, little attention is given about their influences on flora and rural farmland in the western fringe areas of Addis Ababa during the recent past. Hence, effective and efficient planning of satellite town growth and undesirable land-use changes and its impact on the forest and agricultural land requires information about growth trends and patterns amongst other important information. In this regard, the recent integration of GIS with the Shannon entropy method has been useful in the analysis of urban growth trends and predictions (Shenbagra et al. 2019). This method is a computational model that provides the urban growth trend (how much?), direction (from/to which direction/s?), and location of change (where?) analysis with greater specificity than other urban indicator models (Rahman et al. 2011; Singh et al. 2019). In the study area, as urban areas have changed rapidly over the last decade, analysis of urban dynamics has become increasingly common because they can be produced rapidly and are easy for comparative analysis. This study, therefore, aimed at quantifying and analyzing the urban growth-ecology nexus which is driving forest and agricultural land loss in Sebetea-Awas town using an integrated GIS tool, remote sensing technique, and Shannon entropy method.

Data and methods

Study area

The study area, Sebetea-Awas town in the western fringe areas of Addis Ababa, extends between 8° 35' to 9° 05' N and 38° 24' to 38° 45' E, covering an area of 87,600 ha (Fig. 1). The satellite town occupies a very large built-up population, migrant, and evacuated farming communities. It includes fast-growing towns: Sebetea, Alem Gena, Awash, Tefki, and Boneya which cover more than 90% of the total population of the study area. The topography of the study area is characterized by a plain with some mountain ranges in the northern part

with the altitude ranging from 1808 m to 3381 m above sea level.

The study area was among the most ecological destination area in peri-urban satellite towns of Addis Ababa City. The natural vegetation of the study area belongs to the remnant Afromontane forest of the Ethiopian highlands which had survived millennia of human exploitation and land conversions (Friis and Breugel 2010). The forests are found in churchyards, riverbanks, protected areas, and steep slopes. The remnant forest is a mixed dry Afromontane forest which is scattered in the upper canopy stratum of inaccessible and protected areas.

According to the Finfine Zone Socioeconomic profile (FZSeP 2011), the population growth is very rapid due to natural increase, rural-urban migration, and urban-urban migration. During the first population census (1984), the population in the study area was more than 50,000 though there is scarce demographic data of the peripheries. In addition to this, the total population of the study area was 0.12 million in 1994 and it grew over 0.17 million in 2005 and increased by almost two-fold to 0.29 million in 2013 (CSA 2015). Similarly, the authority also reported that following surge of the population to the town's current population almost doubled its 2007 size by crossing over 0.35 million in 2018. However, there are no still true statistics of the current population due to the rapid immigration of peoples from the centers and across the rural areas in the country. It is among very few urban fringe areas in the frontier of Addis Ababa where major urban expansions are occurring. So with this fast-growing number of urban population trends, the municipality has been faced with mammoth challenge for the peri-urban ecological sites and agricultural sector. The study area is a satellite town which attracts massive public residential constructions, investments, factories, and institutions to fulfill the demand of the residents and Addis Ababa populations.

The region is known for its high wheat, barley, pulses, teff, vegetables, and livestock productions and supplying for domestic market consumption particularly to Addis Ababa inhabitants, and for factories. Nonetheless, the forest land and fertile agricultural land have been replacing by various real estate developments, industries, factories, and infrastructural developments which in turn attract several thousands of newcomers to the area.

Research methods and design

This study applied remote sensing, Shannon entropy, software ArcGIS 10.2, and ERDAS Imagine 2014 to assess the spatial extent of peri-urban expansions and urban growth trends since the mid of the 1980s. In addition, an interview with thirty key informants from the aforementioned towns during field observation was conducted to extract qualitative information about the perception of dislocated farmers in the study area.

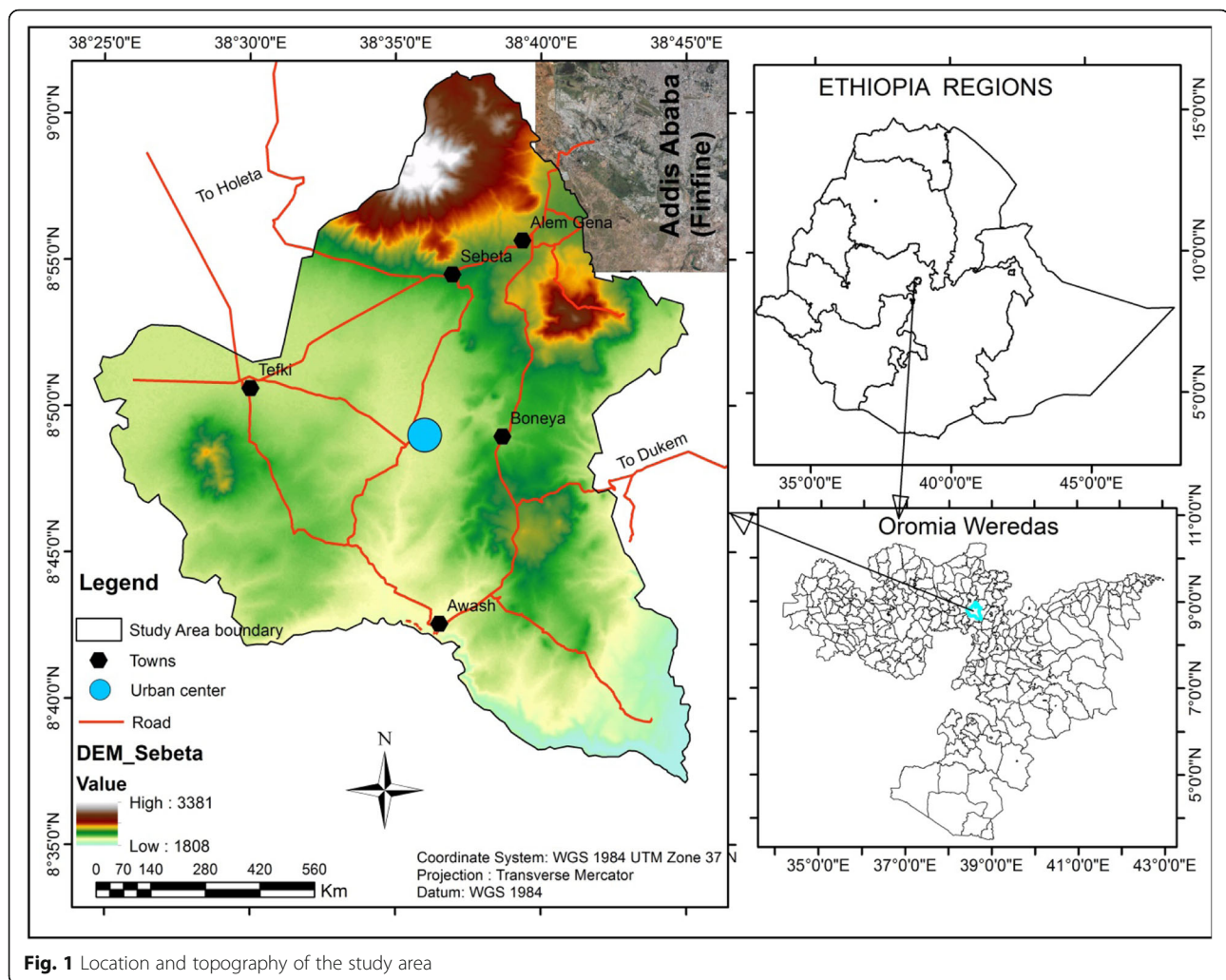


Fig. 1 Location and topography of the study area

Data type and sources

Satellite imageries and ancillary data

In this study, Landsat TM of 1986, ETM+ of 2002, and L8 (OLI) of 2019 were used to extract land-use and land-cover information for Sebeta-Awas town (Table 1). All Landsat imageries obtained free of charge from the United States Geological Survey (USGS) via <https://earthexplorer.usgs.gov/> were cloud-free. ASTER global digital elevation model (GDEM 30 m × 30 m) was freely accessed from US NASA to grasp model elevation of the study area. Topographic maps at the scale of 1:50000 dated in 1984/86 were obtained from Geospatial Information Agency (GIA) to check the position of satellite imageries.

Data analysis

Land satellite image data pre-processing, development of image classification and referencing points

Although the United States Geological Survey (USGS) data center freely provided pre-processed Landsat

scenes, pre-processing techniques were applied to minimize the distortions in hilly areas of the study area. Hence, all Landsat imageries were topographically corrected using the non-Lambertian model for the C-correction of Teillet et al. (1982) with PG-STEAMER 4.2 software. A technique developed by Chander et al. (2009) was considered to correct the radiometric correction (Eqs. 1 and 2). Likewise, we also consulted techniques developed by Richter et al. (2006) and Vermote and Saleous (2006) for atmospheric correction of satellite images in ERDAS imagine 2014 software.

$$LA = \left[\left(\frac{LMAXA - LMINA}{QCALMAX - QCALMIN} \right) * (QCAL - QCALMIN) + LMINA \right] \dots\dots\dots (1)$$

$$PA = \frac{\pi * LA * d^2}{ESUN\lambda * \cos \theta_s} \dots\dots\dots (2)$$

Table 1 Description of data type and sources

	1986	2002	2019	Purpose
Satellite (sensor)	Landsat TM	Landsat ETM+	Landsat OLI	LULC classification
Sources	Earth explorer	Earth explorer	Earth explorer	
Resolution	30 × 30 m	30 × 30 m	30 × 30 m	
Path/row	168/054	168/054	168/054	
Acquisition date	03/26/1986	02/26/2002	02/01/2019	
Sun elevation	53.89042105	53.91455582	51.36869550	
Sun azimuth	98.39366733	118.06159253	131.97553411	
Solar zenith angle	36.10957895	36.08544418	38.6313045	
Earth-Sun distance	0.9975825	0.9901226	0.9853171	
Cloud cover	Free (study area)	Free	Free (study area)	
Image quality	9	9	9	
Google earth image	Yes, 1986	Yes, 2002	Yes, 2019	Ground truth
Ancillary data	Sources			Purpose
Road	CSA			Proxy for
Population (since 1984)	CSA & Municipality			Growth trend
Other socio-economic data	Municipality			Ancillary

After having successfully pre-processed, a land-use classification scheme was carried out considering the USGS classification scheme (Anderson et al. 1976). In addition, field interviews and observations were conducted to collect information from stakeholders. Accordingly, four major land-use and land-cover classes namely built-up areas, urban-peri-urban agriculture, open land, and forest land were identified (Table 2). For this classification, about 520 sampling points were collected from historical Google Earth images of which 320 and 200 points were used for classification and reference, respectively. Finally, the object-based classification technique was applied to minimize the spectral signature confusion of land-use and land-cover classes.

The classified LULC categories with referenced data were compared to evaluate the degree of accuracy output (Lillesand et al. 2008). In this regard, the overall, producer, and user accuracies and Kappa coefficient (khat) were computed after consulted (Lillesand et al. 2008).

Spatial extent, trends and rates of urban expansions

The percentage (P) of transitions in land-use and land-cover was computed by applying equation 3. Using the Boolean operation method, built-up area was extracted from other classes in the ArcGIS environment. Similarly, Eq. 4 formalizes how to compute annual rate (r) of urban growth at different periods, the methods outlined in (Puyravaud 2003). Moreover, gross gains (g) and gross losses (l) were computed from the existing persistence classes.

$$P = \left[\left(\frac{A_2 - A_1}{A_1} \right) * 100 \right] \dots\dots (3)$$

$$r = \left[\left(\frac{100}{\Delta t} \right) * \ln \left(\frac{A_2}{A_1} \right) \right] \dots\dots (4)$$

Where A_1 and A_2 are the area coverage of a land cover at t_1 and t_2 . \ln is the base of the natural algorithm function.

Analysis of the urban sprawl

As to Sudhira et al. (2004) and Rahman et al. (2011), the integration of GIS tool, Landsat imageries, and Shannon entropy methods are techniques to model and monitor rapid urban expansions mainly in a rapid population growth cities. Shannon's urban entropy among different metrics is widely consulted in many studies to quantify urban expansion in a fast-growing region (Kumar et al. 2007; Dekka et al. 2012).

The approach measures the degree of spatial concentration and dispersal of built-up areas over time (Singh et al. 2019). In this study, at 1, 2, and 3 km concentric distances were used and analyzed separately. However, none of them provided clear information about the distribution except the former interval, i.e., 1 km. In line with this using the confirmed concentric interval (1 km) the potential Modifiable Area Unite Problems (MAUP) effects were checked, and the results showed insignificant MAUP problems. Hence, for this study, twenty-five concentric shield rings at an interval of 1 km were designed from the core of the town denoted by letter "A" up to 25 km denoted by letter "Y" for Shannon entropy

Table 2 Contingency table for the year 2019 classified map

		Reference data 2019				Row total	UA (%)
		AL	BA	OL	UF		
Classified data	AL	50	0	0	0	50	100.00
	BA	1	49	1	0	51	96.08
	OL	1	0	50	0	51	98.04
	UF	0	0	0	48	48	100.00
	Column total	52	49	51	48	200	
	PA (%)	96.15	100.00	98.04	100.00		
$K = 0.98$ $OA = 98.5\%$							

Where *AL* agricultural land, *BA* built-up area, *OL* open land, *UF* urban forest. Diagonal elements in italics indicate LULC classes are classified correctly

calculations. These were further divided into four zones: northeast, northwest, southeast, and southwest, to identify urban sprawl direction and growth in individual zones.

Consequently, the average entropy values from the town center for all twenty-five zones, and the above four zones were computed to evaluate the pattern of urban growth over time. In this regard, the Shannon entropy (H_n) technique developed by Yeh and Li (2001) was consulted to measure the patterns of urban growth (Eq. 5). The notation of P_i is the probability of variable occurring in the i th zone and n is the total number of zones. In line with this, change entropy values (ΔH_n) between initial time (t_1) and final time (t_2) was applied to indicate the magnitude of change of urban sprawl in Eq. 6.

$$H_n = - \sum_{i=1}^n P_i \log_e(P_i) \dots \dots \dots (5)$$

$$\Delta H_n = H_n(t+1) - H_n(t) \dots \dots \dots (6)$$

Finally, field verification and validation were conducted to recheck the model output and growth of built-up areas concerning the distance from the town center.

Results

Accuracy assessment

The error matrix report for 1986, 2002, and 2019 classified maps are presented in Table 2. Accordingly, a value of 98.5% overall accuracy and 0.98% of Kappa coefficient value for 2019 classified map was recorded. Likewise, overall accuracies of 95.5% and 97.5%, and associated khat values of 0.94 and 0.97 were obtained for the reference years of classified maps of 2002 and 2019, respectively. Landis and Koch (1977) and Congalton and Green (2009) suggested that the Kappa statistics of a value greater than 0.8 indicate a strong agreement while a value ranging between 0.6 and 0.8 represents a substantial agreement between the reference data and classified maps. Accordingly, the error matrix report for all study periods presented classified maps met the accuracy

requirements and ready to conduct built-up area dynamics (Anderson et al. 1976).

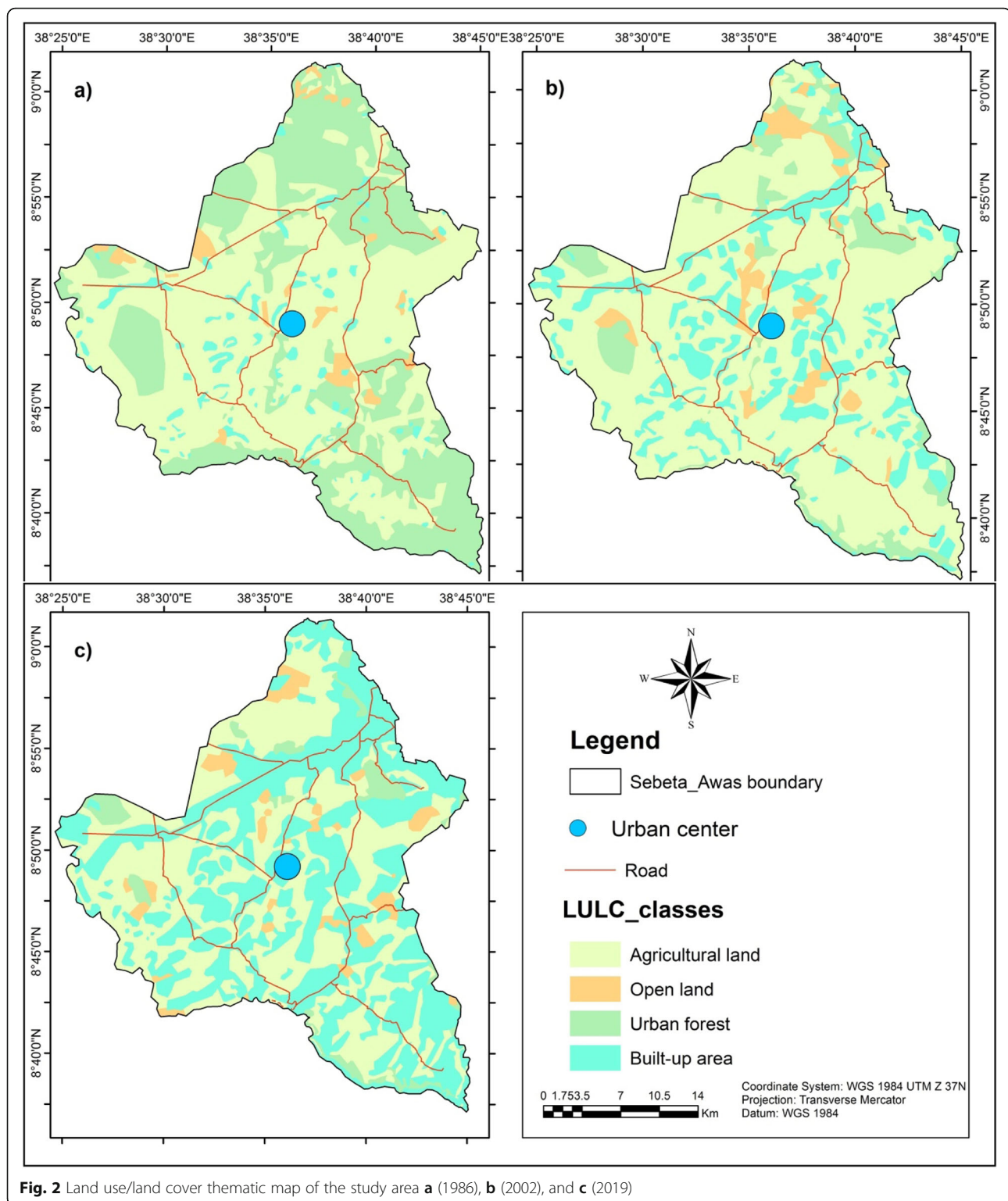
Spatial extent, trends, and rates of urban expansions

Figure 2a–c presents the land use/land cover maps of the study area for the years 1986, 2002, and 2019. Both agricultural land and urban forest were the dominant classes in 1986 roughly covering over 55.25% and 37.32% of the landscape, respectively while in 2002 urban forest had lost its second position to built-up areas (8.78%) (Table 3). Even though agricultural land kept its dominance (66.72%) until 2002, it drastically lost its position to built-up areas (43.35%) in 2019.

The transitions of landscape categories since the mid-1980s in three-span study periods are indicated in Table 3. The trends of agricultural land, open land, and forest land were decreased throughout the study periods except for the former class in 2002 but the rate of decrease was different. The former class expanded to forest area following rapid urban expansion near to town center on croplands in 2002. However, a built-up area rapidly replaced agricultural land following massive constructions, investments, and factories in 2019. Generally, the built-up area has significantly increased which finally resulted in deteriorating forest resources over the past three decades in the study area. The same experience in the study area has also been confirmed that human disturbances due to human settlement expansion and agricultural encroachment towards key ecological areas endanger endemic and endangered species in Merhabete district, Central highlands of Ethiopia (Abrha et al. 2017).

Percentage change and rate of built-up area expansion

In the first study period (1986–2002), the built-up areas exhibited a net positive change of 15.2% while a net decline of urban forest land 28.54% (Table 3). Built-up areas recorded total gains of 15.58% of which 10.17% from agricultural land and 4.95% from forest land (Fig. 3). Similarly, agricultural land gained 21.4% of forest land. During this period, built-up areas increased at an annual rate of ~1.2% with substantial gains from the two crucial classes



(agricultural land and forest land). In terms of persistence considering their areal coverage, only built-up areas avoid a loss to other classes and retain its original cover (4.2%) though agricultural land persisted (43.61%) but lost

10.17% and 1.1% to built-up areas and open land, respectively.

In the second study period (2002–2019), built-up areas and agricultural land showed a comparably higher

Table 3 Land use/land cover transitions for each study span periods in %

	AL	BA	OL	F	Total	Losses	Net change
1986/2002							
AL	43.61	10.17	1.06	0.40	55.25	-11.63	11.47
BA	0.36	4.19	0.01	0.00	4.56	-0.37	15.21
OL	1.35	0.46	0.81	0.25	2.88	-2.06	1.86
F	21.40	4.95	2.85	8.13	37.32	-29.20	-28.54
Total	66.72	19.77	4.74	8.78	100.00	-43.26	0.00
Gains	23.10	15.58	3.92	0.65	43.26	0.00	
2002/2019							
AL	38.62	25.00	2.46	0.64	66.72	-28.10	-23.37
BA	0.63	19.02	0.10	0.02	19.77	-0.75	27.91
OL	1.92	1.61	1.17	0.03	4.74	-3.56	-0.28
F	2.17	2.06	0.72	3.83	8.78	-4.95	-4.26
Total	43.35	47.68	4.46	4.51	100.00	-37.36	0.00
Gains	4.73	28.66	3.28	0.69	37.36	0.00	
1986/2019							
AL	28.45	25.48	1.05	0.27	55.25	-26.80	-11.90
BA	0.20	4.33	0.02	0.00	4.56	-0.23	43.12
OL	1.09	1.21	0.31	0.26	2.88	-2.57	1.58
F	13.61	16.66	3.08	3.97	37.32	-33.35	-32.81
Total	43.35	47.68	4.46	4.51	100.00	-62.94	0.00
Gains	14.90	43.35	4.15	0.54	62.94	0.00	

The diagonal elements in italics indicate the unchanged LULC classes

magnitude of net change (+27.91% and -23.37%, respectively) but to opposite directions. Built-up areas increased at an annual rate of 5.5% with significant gains 25% from agricultural land and substantial gains 2.06% from forest land, which was high above the national urbanization rate of 4% (Fig. 3). This might be due to socioeconomic, political, infrastructural developments, and demographic factors.

Over the last three decades (1986–2019), rapid change in built-up areas especially informal settlements and public residential and mixed residential areas showed a net positive increase from 27.91% during 2002–2019 to 43.12% during 1986–2019. In this period, built-up area increased by four times as compared with the previous period (~15.5% per annum) significantly gains 25.48% and 16.66% from agricultural lands and urban forest, respectively (Fig. 3). In contrast, built-up areas rejected being converted to or loss to these and other classes, this possibly due to massive construction of new houses informal settlements along river banks, forests, and far on agricultural lands. This indicates the urban area that has grown approximately four and three times over the past three decades. Consequently, Fig. 3 confirms the rapid rate of urbanization and settlements on agricultural

lands and urban forests further triggered the economic, political, ecological, and the environment in general (Abebe et al. 2019; Deribew 2019).

However, unlike other studies conducted in big cities, metropolis, megalopolis, and conurbation in this study (small city), the designation of 1 km and four quadrants have been confirmed that does not subject to potential modifiable area unit problems (MAUP). In this regard, the researcher genially consulted literature and urban planners on the potential MAUP in the study area. The results found at 2 and 3 km distances of concentric rings did not provide clear information following the distribution of small growth villages and towns. Following this, 1 kilometer (1 km) concentric has been designed and comprehends the nature of urban growth in the study area which was initially slow later being swift to the outskirts of the urban center. Hence, at 1 km, concentric findings were far better compared with 2 and 3 km concentrics. Therefore, based on the analyzed result, it is concluded that MAUP are not impacted.

The magnitude and shifting of urban growth

The built-up area in 1986 was 4.6% of the total and increased to 19.77% in 2002 and finally heightened to 47.68% by the year 2019. Figure 4 shows built-up area zones in concentric rings in 1986, 2002, and 2019. The rings were covered up to 25 km (“A” in the center to “Y” at the periphery) from the center, covering the entire study area. Figure 5 (overall study area) indicated the distribution of the percentage of the built-up area within each of the rings for the years 1986, 2002, and 2019. It indicates the temporal change of built-up areas over the past three decades (1986–2019). In this regard, urban growth was higher close to the center (B–E and F) then after drastically declining to the periphery shown in 1986. Similarly, in the year 2002, the magnitude of urban growth was increased from where the built-up area stoppage in 1986 and started to decline to the remote periphery (S to Y). However, in 2019, urban growth was rapidly increased to the periphery (F to Y) than former study periods.

Figure 6 indicates the percentage of zone-wise distribution of built-up areas within each concentric ring over the past three decades in the study area. The result revealed a heterogeneous distribution of built-up areas in all zones. In the former period (1986), colossal built-up areas in all four zones were concentrated close to the urban center of the town (A) but gradually decline towards the outer parts of the town. However, in the second study period (2002), urban growth was significant around the center in all zones except in the northeast zone at 500 km. This was later increased to the outskirts though the percentage at which they grew was different. In contrast to 2002, the growth of new urban areas to the outskirts of the center on cultivated land and forest land was terrifically observed in all zones in the recent

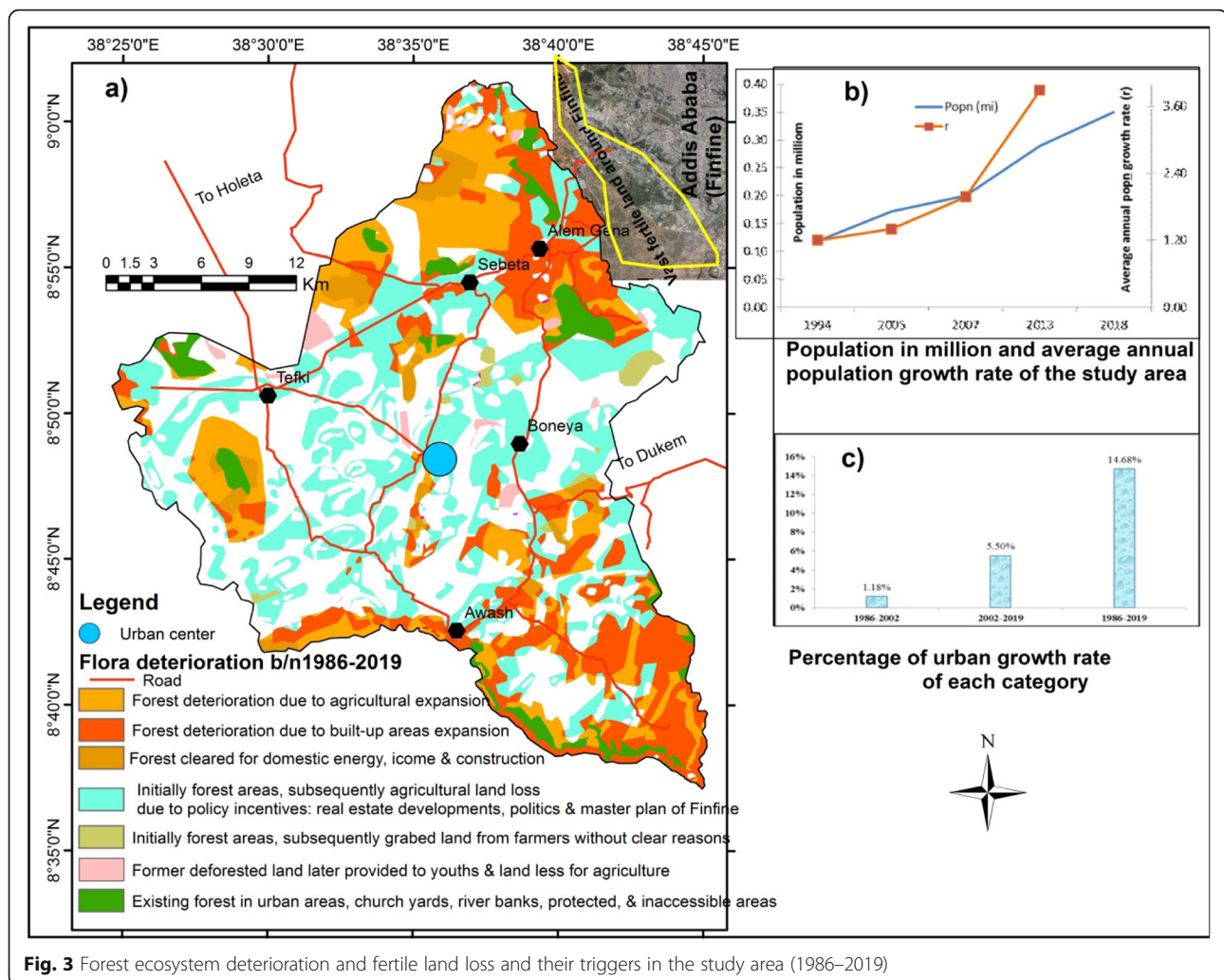


Fig. 3 Forest ecosystem deterioration and fertile land loss and their triggers in the study area (1986–2019)

year (2019). This implies that built-up area concentration around the town center in 1986 later grew to the outer part in 2002 and very swift grown to the outskirts of the town in 2019.

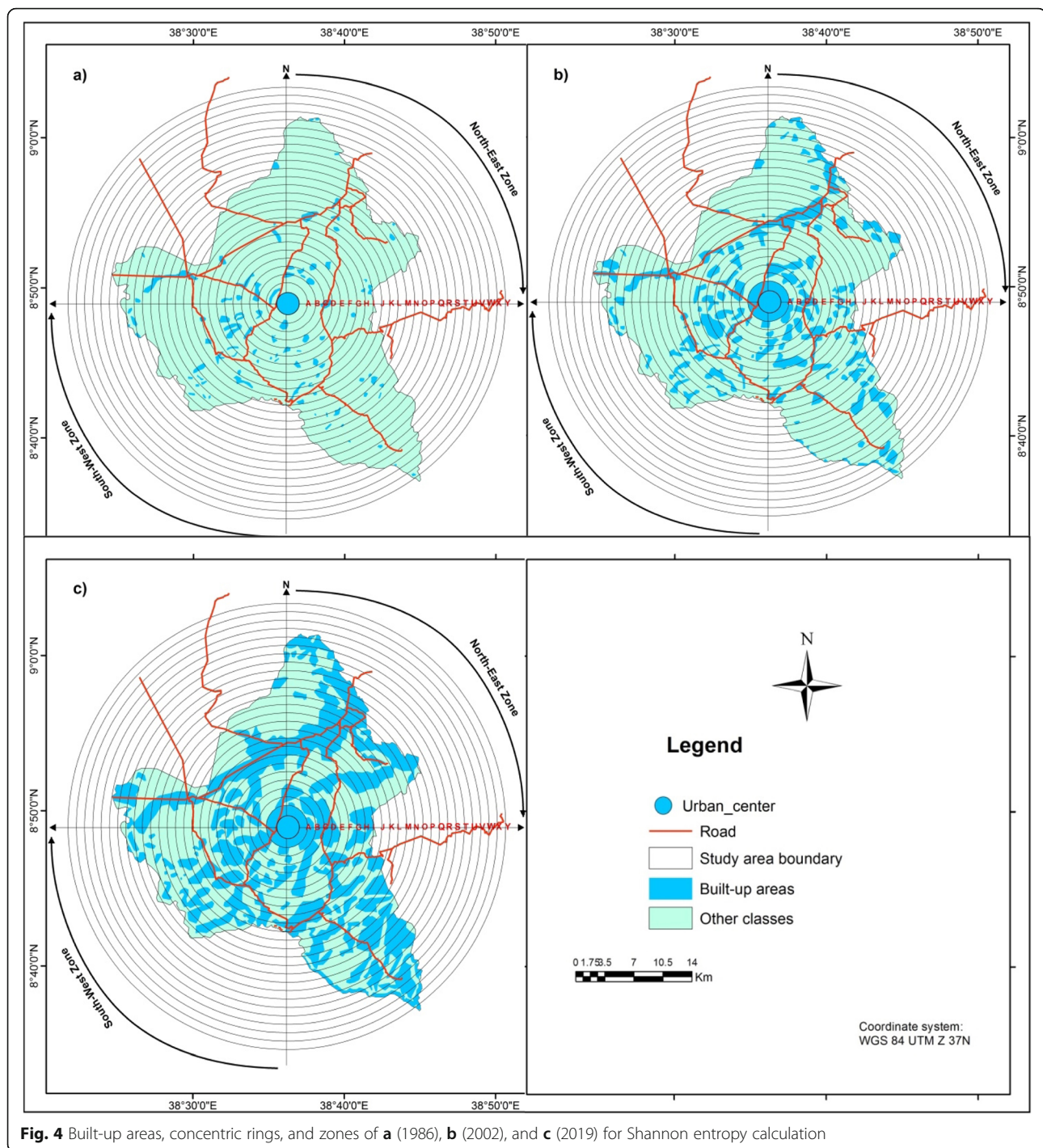
Figure 7 (overall entropy values) and Fig. 8 (zone-wise entropy values) indicated the entropy values for the distribution of the percentage of built-up area for the years 1986, 2002, and 2019. The average entropy value in 1986 was higher in B and G (due to the concentration of built-up areas) while the value has been slightly increased to the outskirts in 2002 and concisely increases to the periphery in 2019 (Fig. 7). The result also indicated that the average entropy values of 0.202 in 1986, 0.589 in 2002, and 0.996 in 2019 which are closer to a lower limit of $\log(n)$ (Fig. 8). The consistent increase in the value of the entropy index indicated that there is an increase in urban sprawl, and development trends to be more dispersed. In 1986, the highest average entropy value was recorded in the southwest (0.061) while the loss was observed in the southeast zone (0.044) and

northeast zone (0.043) (Fig. 8 and Table 4). In contrast to the former period, the average entropy value was highest in the southeast (0.172) followed northeast (0.156) while the lowest recorded in the southwest (0.131) and northwest (0.13). This shows that the urban growth trend was shifted from southwest in 1986 to southeast in 2002. Nevertheless, the current urban growth trend (2019) is shifted from southwest to southeast and northeast with an average entropy value of 0.292 and 0.274, respectively.

Discussion

Spatial extent, trends, and rates of urban expansions

The study reveals that there is a remarkable urban sprawl in the Sebeta-Awas town, western fringe areas of Addis Ababa, over the past three decades (1986–2019). The built-up area was dominating the gains while forest and agricultural land were dominating the losses and suggesting these changes may have been driven by a combination of biophysical, socioeconomic, and policy



factors. Rapid urbanization and expansion of settlement (43.12% net increase) may have further triggered the urban ecosystem, mostly gaining massive areas from agricultural land (25.48%) and forest (16.66%) over the past three decades (1986–2019). Though, agricultural land experiences a net loss (−26.8%) during the study period it was found to be relatively persistent land cover class (28.45%).

The former study period (1986–2002) was characterized by a rapid increase in agricultural land due to population growth. A similar study reported that demographic pressure in the urban fringe areas of Addis Ababa resulted in declining landholding size (~2.4 ha per household) and the forest was cleared for new settlements and cropland (Deribew and Dalacho 2019). In this regard, 21.4% of forest land was initially converted to

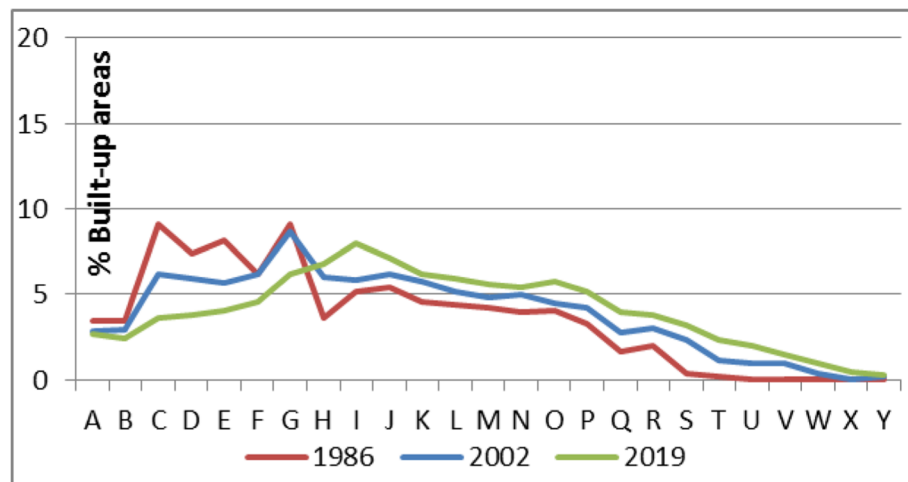


Fig. 5 Percentage of the urban built-up area within each ring

agricultural and this in turn substantially converted to the built-up area (10.17%). Furthermore, this might be related to nation-wide planned resettlement and villagization/urbanization programs that were carried out by the Ethiopian government (Woube 1995; Getahun et al. 2017; Deribew 2019). The same finding has also been reported at Mordvins in Western Europe that the program resulted in the depletion of biodiversity (Shchankina 2019). Likewise, rural land reform in the mid of 1970s where redistribution of land to landless

peasants may have resulted in further fragmentation of forest. The second study period (2002–2019) has returned to the dominance of the built-up area at the expense of mainly agricultural land. The area witnessed the rapid urban sprawl which has increased twice from net mere of 15.21% during 1986–2002 to 27.91% during 2002–2019. The built-up area gained from agricultural land roughly covering 35.17%, of which 10.17% during 1986–2002 at an annual rate of 1.2% and 25% during 2002–2019 at an annual rate of 5.5%. The overall built-

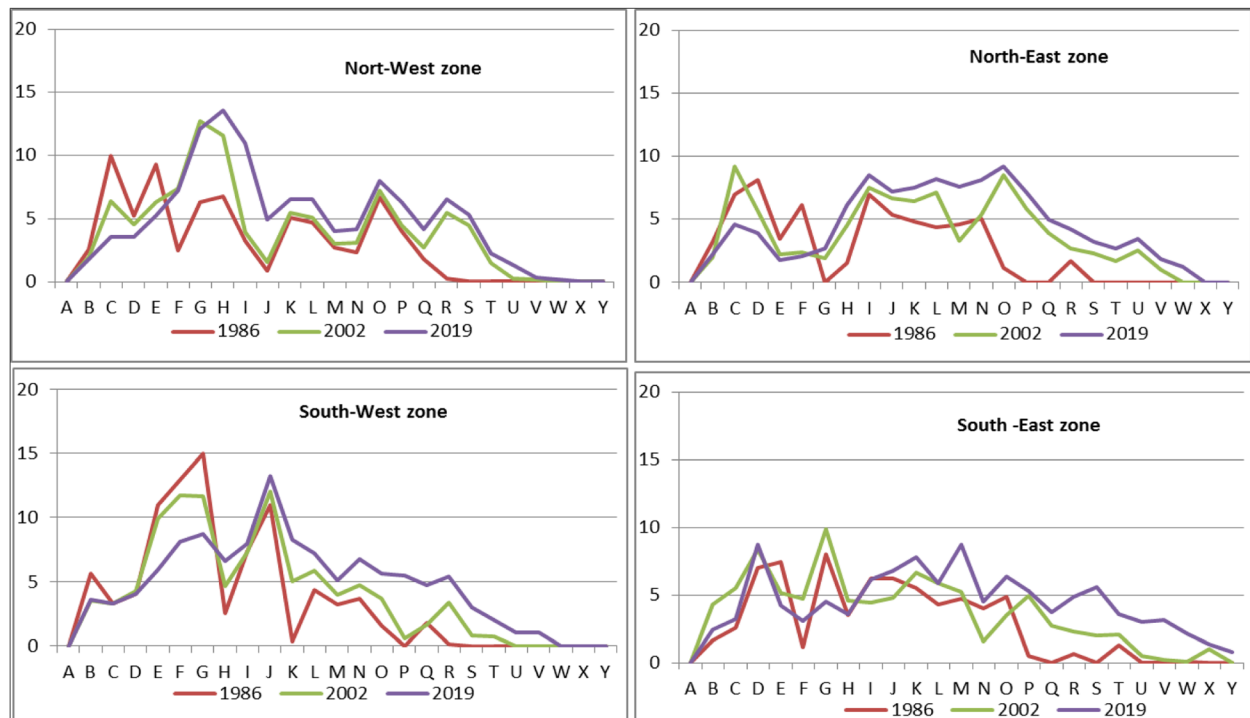


Fig. 6 Percentage of zone-wise distribution of built-up area within each ring

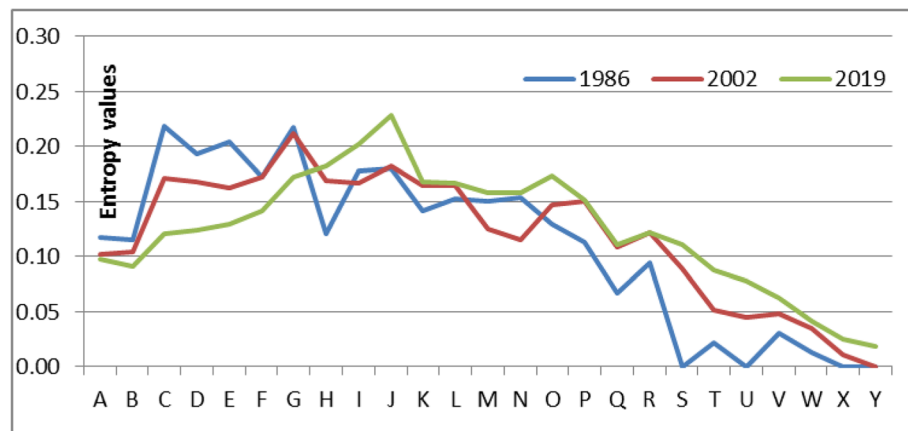


Fig. 7 Distance from the town center and zonal entropy values in each concentric ring

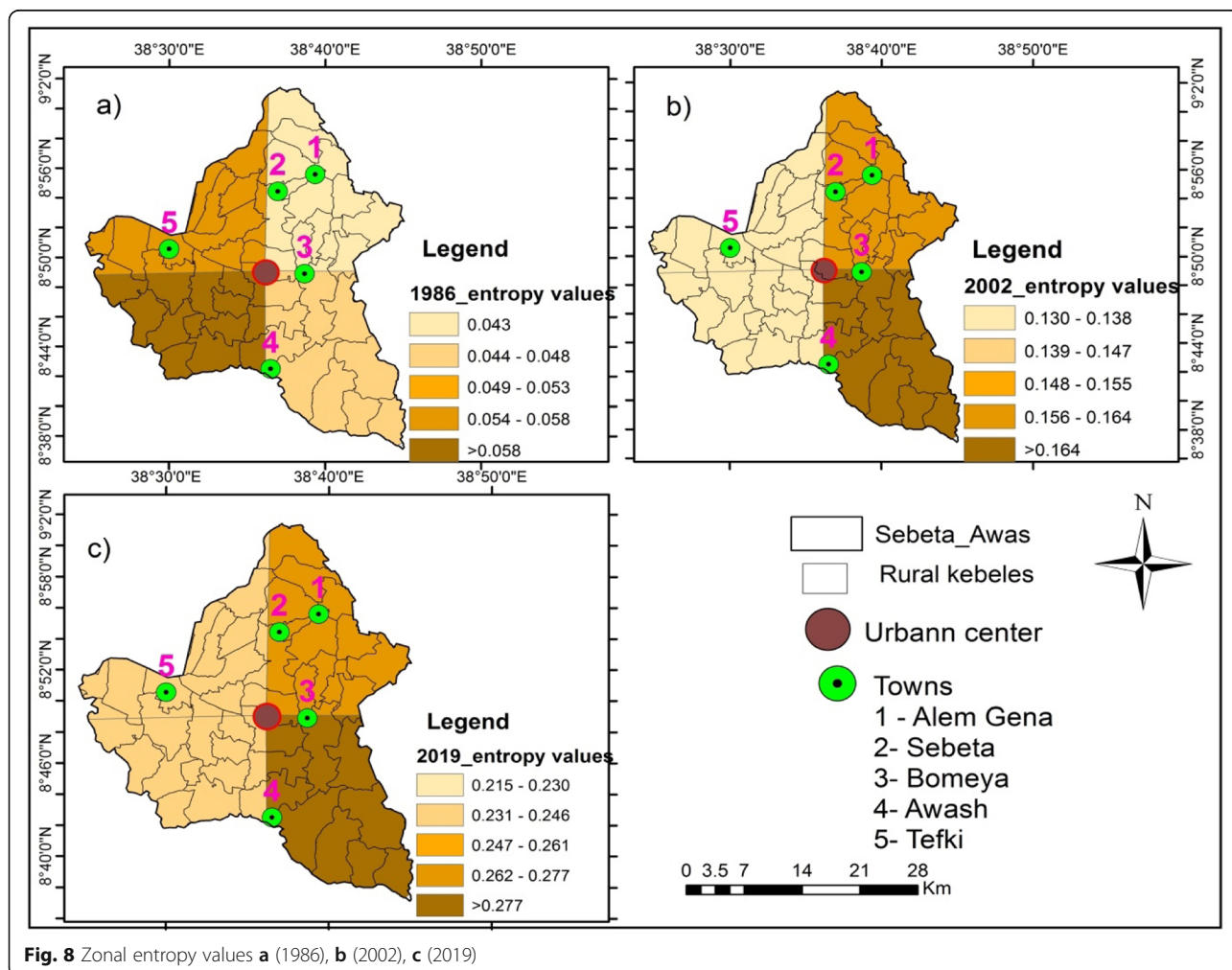


Fig. 8 Zonal entropy values **a** (1986), **b** (2002), **c** (2019)

Table 4 Zone-wise entropy values in 1986, 2002 and 2019

Year	Zones				Total
	Northeast	Northwest	Southeast	Southwest	
1986	0.043	0.054	0.044	0.061	0.020
2002	0.156	0.130	0.172	0.131	0.600
2019	0.274	0.215	0.292	0.216	0.996

up area growth in the study area is ~15% per annum which is five times the country's urban growth. Several triggers such as socioeconomic, demographic, government infrastructure development, and investment policies stimulated massive conversion of fertile land in the study area. Following the replacement of "a neo-liberal" economic development over socialist policy in the early 1990s was among the main catalyst behind transformation was an incentive for local and foreign private investments, expansion of infrastructure, and very rapid urbanization in the study area. The Sebeta-Awas investment office has also confirmed that about 549 household farming community was evacuated from their land during 2007–2010 and compensated cash not more than Birr 39.72 million. The key informants reported that they complained about low consumption and lack of other economic options to make a living. Thus, the majority of the evacuated residents have fled to live informally along the river banks and forest areas, i.e., in the northern and southern edges. In this regard, more than 90.2% of forest loss due to agricultural encroachment, built-up area expansion, and construction was widely observed in Sebeta and Alem Gena areas, of course, Northeast zone in this study. In this zone, the study showed that carbon density is higher viz. 293 tons/ha in the ecologically protected area (Woldegerima et al. 2017). As to soil erosion features Eucalyptus and Junipers forests which are among the dominant forest cover in the study area found to be aggravated to the soil erosion problem. This has also resulted in eco-hydro depletion which further exposed to environmental disruptions.

The magnitude and shifting of urban growth

The urban growth patterns observed in the study area align well with the regional biophysical dynamics particularly topography, socioeconomic, and policy changes in the country. These triggered the distribution, concentration, and growth of the built-up areas in the study periods: 1986, 2002, and 2019. A very high concentration of built-up area at an average radius of 6 km which was very close to the town center ('A' to 'F') observed in 1986 was mainly due to a combination of low demographic pressure, socioeconomic (market), infrastructures, and agricultural land-holding security as compared with other study periods. Market, commercial areas, general service areas, and mixed residential areas were relatively found in the town

center during the former period. However, later built-up areas were constructed outskirts of the center along with road and river networks, plain area, and fertile land at a rapid rate. As a result, the average entropy increased as one moves away from the center (A); so, the study area experienced a compact built-up area within the radius of 7 km (till ring 'H') in 1986 and it becomes dispersed to the outskirt in the other periods. The average entropy value of 2002 became more than that of the former period by 3 km (J ring). Similarly, the average entropy value after J ring was very high in the later study period (2019) as compared with the former study period (1986) and middle study period (2002) due to development activities in the peripheral areas. Similar study has also seen in the middle of Nile delta in Tanta and Quttour, where fertile agricultural land decreased by 13.01% as a result of swift urban expansion during 1972–2005 (Belal and Moghanm 2011).

Similar finding was reported by Dadi et al. (2016) that excessive demand of the land by investors fuelled urban sprawling at the expense of prime agricultural land in the outskirts of the newly industrializing town of Dukem. They have further marked that the number of individual industries grew from less than 50 before the designation of Dukem town as industry zone in 2005, to over 642 units in 2011. Therefore, urban displacement coupled with rapid rural-urban migration to the capital and back to the fringes areas of peri-urban areas of Addis Ababa led to the expansion of built-up areas on cropland and forests were the net losers in peri-urban areas of Addis Ababa (Samson 2009; Leulseged et al. 2011; Lohnert 2017). Similarly, very rapid urban expansion following the incentive of local and foreign investments, rapid construction and infrastructural developments heightened urban growth rate by ~15% in 2019. In this regard, more than 25% of the study area's agricultural land was replaced by a built-up area during 2002–2019.

Consequently, the average entropy value in 1986 was increased from Tefki town in the northwest and Sebeta town in the northwest to Awash town in the southwest. However, average entropy value due to rapid urban growth was later shifted to the rural peripheries of Sebeta and Alem Gena towns in the northeast in 2002 and this was finally heightened to the east of Awash town, and Boneya town in the southeast zones in 2019. Huge incentive investments in building public houses, industries, horticulture, commercial areas, and other infrastructural developments thereby attracted millions of employees triggered the urban growth. This implies that the satellite town experienced greater dispersal land development mainly between 2002 and 2019. In this regard, as Geopolitics in the landholding system, these investments have been undergoing in the administration of the Oromiya region which led several conflict and peace crises in Finfine Zuria (surrounding). As to

Deribew and Dalacho (2019) ecologically prioritized areas and fertile land, Finfine Zuria has been substantively converted to built-up areas. Of course, the average entropy of 1986 was one-third of 2002, and later exceptionally escalated in 2019 (Table 4). In this regard, it has been argued that when the entropy value of any later year becomes more than that of the earlier years, greater dispersal of development is indicated (Yeh and Li 2001; Deka et al. 2012). On the other hand, as long as the entropy values of any study remain less than that of the later years, it indicates compactness of development.

Thus, as the town expanded, residential and mixed residential buildings situated in the town center were disposed to commercial area use, as a result of which people residing in the city center (e.g., in 1986) migrated to the outskirts of the town which was an additional reason for the climax of entropy values mainly in 2019. In the recent years, many real estate developers built very massive new residential and commercial areas, horticulture and huge factories on agricultural lands following major roads in Alem Gena, Awash, Sebeta and Boneya towns, indicating the towns grew in east direction (northeast and southeast) with high sprawling characteristics (~0.6 entropy value). The crisis was further complicated following the new master plan of Addis Ababa was about to be implemented had dislocated many thousands of people (for investment purpose in Addis) and were settled in the above towns (Fig. 8 and Table 4). This resulted in a remarkable expansion of built-up areas while pressure continued on rural farmland and forest land. The propagations of private investments, horticulture, real estate developers in east Awash, Boneya, Sebeta, and Alem Gena have fascinated a reverse movement of people where urban-rural migration was the main trigger. This was evidenced by rapid urban sprawling by dislocating farming communities (25.48%) and clearing forest (16.66%) which grows at an annual rate of ~15%. This may have a far-reaching impact on eco-hydro pollution, urban forest degradation, climate change, ecological deterioration, and economic crisis.

Conclusion

The applications of GIS, open-source satellite images, and entropy methods reveal that the Sebeta-Awas town has experienced severe reductions in forest and agricultural land due to urban sprawl over the past three decades with the lack of proper development control and management. The main triggers of rapid urban growth were the intermingling of demographic dynamics, government policies (politics on the new master plan of Addis Ababa/ Finfine), biophysical processes, and socio-economic crisis in the town center. The titanic conversion of peri-urban agriculture, rural farmland, and forest

land to the built-up areas may have an impact upon urban ecosystem depletion and economic crisis.

As to ecological deterioration, the remaining dry Afromontane forests are found in an inaccessible area on the west, south, north, and northeast zones of the study area. However, rapid urbanization and the infrastructural network would drive further forfeit due to the livelihood challenges of the recently migrated poor from the rural and urban areas. Hence, forest clearance for cultivation, settlements, domestic energy, and income generation as evidenced by recent urban growth rate (~15% per year) may result in total ecosystem depletion on the zones. Local climate change and soil erosion have absolute linkage with the presence and absence of forest resources. To ensure a sustainable supply of ecosystem services and maintain a balanced urban environment, all ecological significant areas in the study area should be ecologically networked and diversified. Therefore, the assessment of ecosystem services provided essential information for effective ecological planning of the existing and potential green areas in terms of species composition and interconnectivity.

The study also implies that the recent government investment policy and infrastructural development have further increased the vulnerability of peri-urban agriculture and rural farmland to built-up population and heightened food insecurity through inflation on the price of crops. Following this, some towns namely, Awash, Sebeta, Alem Gena, Boneya, and Tefki in the zonal rings of the study area have experienced an unusually high degree of urban sprawl due to land speculation. This wave of urban expansion in an anticlockwise thereby rapid urban growth in the study area may result in an economic crisis. Consequently, unstoppable evacuation of farming communities in the fringe areas due to urban expansion is expected to worsen shortly unless hostile policy revision and management actions are undertaken. Therefore, the government officials, planners, and policymakers can use the methods and the results of this study to control and monitor such irregular development patterns for protecting the urban ecosystem and economy by making better use of land resources in the urban fringe areas of Addis Ababa particular for Sebeta-Awas town. Finally, very high-resolution satellite imageries due to financial constraints are missed in this study. Therefore, the author directs using very high-resolution imageries conducting future scenarios models from experienced countries would be crucial to conciliate the rapid peri-urban expansions with urban forest ecology and rural farmland thereby rehabilitate ecological loss in the satellite towns.

Abbreviations

CSA: Central Statistical Authority; FZSeP: Finfine Zone Socio-Economic Profile; GIA: Geospatial Information Agency; GIS: Geographic Information System; LULC: Land use and land cover

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Author's contributions

KT has designed the study, collected all data, carried out fieldwork, analyzed satellite imageries, and interpreted the document of the manuscript. Moreover, KT has contributed all literature work, reviewing, and editorial works. Therefore, KT is the only author of this manuscript. All author(s) read and approved the final manuscript.

Availability of data and materials

All data are included in the manuscript.

Ethics approval and consent to participate

Not applicable.

Consent for publication

I agreed to publication in the journal of Ecological Processes.

Competing interests

The author declares that he has no competing interests.

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