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Research article

Measuring urban expansion pattern using spatial matrices in Khulna City, Bangladesh

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ABSTRACT

Khulna, the third-largest metropolitan area in Bangladesh, has become a potential site for the polycentric urbanization for multiple mega-projects. Measurement of urban expansion is essential for regulating haphazard growth and achieving effective management. This study aims to quantify and compare the urban expansion pattern of Khulna City Corporation (KCC) and surrounding areas' development hotspots. Landsat remote sensing images of 1990, 2000, 2010 and 2020 were used to perform supervised classification using Geographic Information System (GIS). To quantify urban expansion, we compute Annual Urban Expansion Rate, Urban Expansion Intensity Index, and Urban Expansion Differentiation Index. Although annual urban expansion in the study area was slow during the first two decades, it accelerated to 6.76% during the last decade. 48% of the total built-up areas have grown during 2010–2020 alone. Even though KCC experienced continuous urban growth over a thirty-year period, after 2010, the rate of urban expansion in peripheral areas exceeded that of KCC. Transboundary and intra-regional transportation and economic corridor development, establishment of economically potential zones (EPZ), urban to rural migration, availability of rich agriculture hinterland, low land price and several direct transportation links between the core and periphery are the major influencing factors of peri-urbanization.

1. Introduction

Rapid population growth, urbanization, and industrialization paved the way for spontaneous and unrestrained urban expansion in developing nations [1]. By 2050, the urban expansion rate in Asia and Africa will be 2.5% [2]. The cities of the developing nations represent different patterns of urban expansion and suburbanization. Urban expansion can be broadly classified as infill, expansion, and outlying. Generally, "infill" development occurs where sufficient public facilities such as water, sewer, electricity, and roads are already in place and the spatial location attracts both population and economic activity, resulting in dense and concentrated physical development within the city limits. "Expansion" occurs in existing urban patches as urban sprawl. Beyond the urban fringe, "outlaying" urban development occurs when completely undeveloped areas become developed [3]. Polycentric development is another type of urban expansion pattern that is compact and expands along a network with less clearly defined boundaries. South Asia's urbanization follows the "Desakota" pattern, in which urban and rural functions converge in peri-urban areas [4].

Urban expansion patterns of various cities differ around the world. Urban expansion may occur as a result of either the continuous

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growth of existing cities or spontaneous development away from existing the urban core [5]. Rapid population, industrial, and commercial growth led to the urbanization of 41 Indonesian cities [6]. The business and housing development program, the land reform program, and dollarization of the economy led to the conversion of farmland, grassland, and forest into urbanized areas in the Gweru city of Zimbabwe [7]. Nigeria's capital city experienced an average urban growth rate of 6.7% in every direction of the city following dispersed and fragmented transportation corridors [8]. The development of public, commercial, and industrial land accelerated urbanization in Shanghai [9]. Mangalore city in India exhibits infill and compact urban expansion due to the industrial special economic zone, technical and physical development, and the availability of agricultural lands for expansion [10].

Bangladesh is undergoing rapid urbanization [11]. The capital city Dhaka is 11th largest megacity experiencing urban growth 81.54% [12]. However, not only Dhaka but the urban growth of secondary cities, even municipalities of Bangladesh are also rapid as well [11]. Besides the urban dynamics of megacities, recently the mid-sized cities are gaining attention to the researchers. Roles and economic performances of Chinese mid-sized cities [13,14], Polycentrism of European mid-sized cities [15], role and the perspectives of medium-sized cities [16], growth factors of United States' small and mid-sized cities [17], network potential as renewal strategy of Swedish medium-sized cities [18], changing hierarchy of mid-sized cities in England and Wales [19,20] and urban areas within national network of mid-sized cities of Spain [21] are a few studies that analyze different aspect of urban dynamics of secondary cities. Likewise, it is pragmatic to explore the growth dynamics of mid-size cities of growing economies such as Khulna city, Bangladesh.

Khulna is the third largest administrative and mid-sized city of Bangladesh demonstrates infill, and expansion urban growth pattern [22]. However, in recent years, the city has simultaneously experienced urban expansion in suburban areas [23] and shrinkage of urban core [24]. Though the city's nature is compact like other mid-sized cities [25,26] but is experiencing polycentric expansion influenced by potential primary factors such as development of transboundary transportation and economic zones [27], intra-regional transportation and economic corridor [28], revitalization of industrial sector [22]. These factors are triggering Khulna city to expand and suburbanize. People of higher and middle-income are speculating valuable agricultural land and expecting benefits from future suburbanization. This mechanism is resulting haphazard urban development, destroying valuable agricultural lands and damaging the environment. Decision makers and city authorities often overlook the situation and do not consider suburban planning as a major concern. This paper is an endeavor to explore the core versus suburban land use dynamic, which in turn, can be used for land policy formulation to control haphazard suburbanization and speculative land transformation.

The aim of the study is to quantify urban expansion of Khulna city and its peripheral areas and to explore the influencing factor of the urban transformation. The major objective of the study is to assess and compare urban expansion pattern of Khulna city and its surrounding areas over a thirty-year period. The second objective of the study is to explore the influencing factors as well as to identify the spatial location of future development hotspots. The study utilized Landsat satellite remote sensing (RS) data of 30 m resolution of 1990, 2000, 2010 and 2020. Maximum likelihood supervised classification has been used to classify land use.

To validate the image classification statistical analysis such as Kappa co-efficient, overall accuracy, producer accuracy and user accuracy were applied along with ground truth check using Google Earth Pro. GIS-RS analytical technique and spatial matrices are efficient and effective process to track urban growth which has been used in several researches [29–32]. This study used Annual Urban Expansion Rate (AUER) [33], Urban Expansion Intensity Index (UEII) [29,30] and Urban Expansion Differentiation Index (UEDI) [31]. One of the major limitations of this study is the use of low resolution (freely available) raster images. Secondly, a total of 160 random points were taken as reference points. Use of high-resolution images along with more reference points could have increase the image classification accuracy.

There are a number of studies that performed only to explore the effects of urban expansion: impact of urban expansion on waterbody [34], LULC spatio-temporal consequences for Khulna city [35], and urban growth analysis and prediction using Markov models for Pabna municipality of Khulna division [36], mega-region transformation of Khulna city [37]. However, to the best of our knowledge, there is no study that analyzed urban expansion pattern quantitatively and explored the factors of urban expansion of mid-size cities of Bangladesh. This study is an initial step in analyzing the urban–suburban dynamics of Khulna, a mid-sized city of Bangladesh. The study can help the city development authorities and decision makers to improve urban governance, manage urban growth in a sustainable way as well as facility improvement based on population redistribution due to urban expansion.

2. Methods and materials

2.1. Study region

Khulna is the third-largest administrative, industrial, and commercial center of Bangladesh. The urban core is surrounded by rich agricultural hinterlands and polycentric peri-urban areas. The average annual population growth rate of Khulna division was 1.48% in 2001, 0.65% in 2011 and 0.93% in 2022 [38]. The population count of Khulna district was 2,378,971 in 2001 and 2,318,527 in 2011 which shows a decreasing population trend [39]. The population of Khulna city decreased from 1255,000 in 2001 to1082,000 in 2011 [40] with 36% living below the upper poverty line [41]. The population count of Khulna city reaches at 718,735 in 2022 [38], which is a result of the declining industrial sector. Population decreased as a result of a change in the definition of urban area due to damage of industrial sector [40].

Khulna district is a disaster-prone region. Residents of the city's outskirts face cyclone and flood every year [42]. The Rupsa and Vairab rivers formed the boundary of Khulna city. There are approximately 88 industries in the city's core and peripheral areas. There were worked 2553 industrial workers in Khulna, of which 80% worked in Jute mills [40]. However, these Jute industries are periodically subjected to a privatization policy regime that has nearly destroyed the sector since 1990, resulting in negative population growth after the year 2000. After 2010, however, Industrial Policy 2010 began to restore the industrial sector [22].

In 2014 began the construction of the Padma Multipurpose Bridge, an intra-regional transportation and economic corridor, which influences the urban growth of Khulna city [28]. The Khulna-Jessore bypass and the Khulna-Mongla rail link, which connect Khulna city to the Padma Multipurpose Bridge, represent a significant step forward for urban development. These transportation and economic corridors expedited transboundary and intraregional trade, industrialization, and the development of economic potential zones (EPZs) (Fig. 2) [27]. The city administration has already planned multiple development projects to enhance urban services and transportation infrastructure [43]. Population immigration and private entities attracted by low land prices and availability of land to develop in the periphery [44]. The selected study area has two parts: (i) KCC is the urban core, and (ii) 5 km buffer of urban core as periphery (Fig. 1). As the target of the research is to measure urban expansion, there is a few possibilities to expand the city on agricultural lands beyond the buffer.

2.2. Collection and preparation of data

To perform analysis, Landsat remote sensing data from USGS (Table 1) and country data from DIVA-GIS were collected. For the years 1990, 2000, and 2010, Landsat 4 and 5 versions and for year 2020, Landsat 8 version were acquired using a raster image format.

To cover the entire study area, 137 Path-44 Row and 138 Path-44 Row raster tiles are required. The cloud cover remained between 0 and 10%. The downloaded raw raster images were band composited and mosaicked where two raster tiles were needed.

2.3. Images classification and accuracy evaluation

Maximum likelihood supervised classification has been applied to classify the image in four land use categories: (i) waterbody that includes pond, river, lakes and all other sole water areas; (ii) agriculture includes agriculture land, low height forest land, grassland, open spaces with grass and other lower vegetation; (iii) dense vegetation includes dense forest land, dense tree garden, natural dense

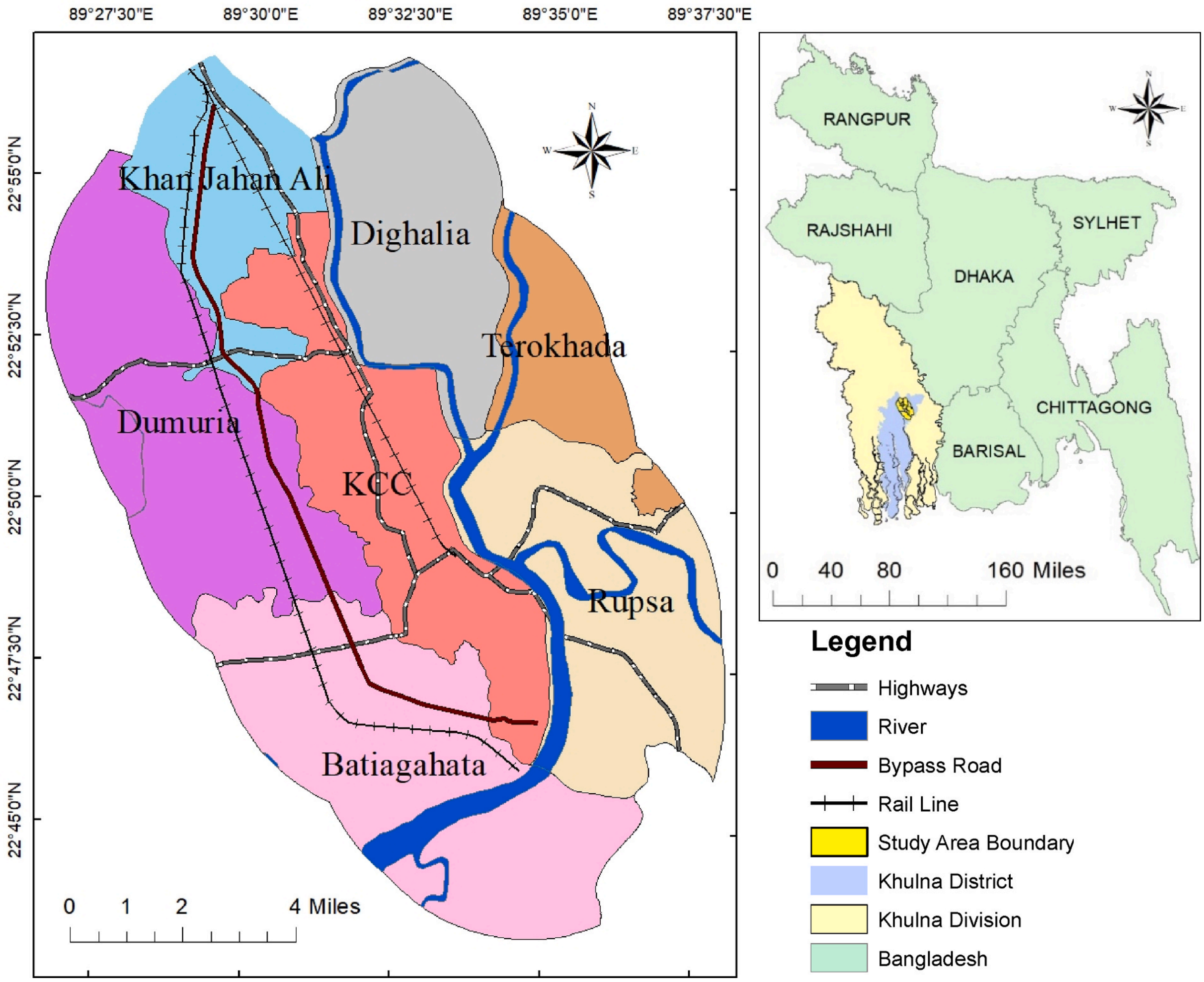

Fig. 1. Study region locating urban core and periphery.

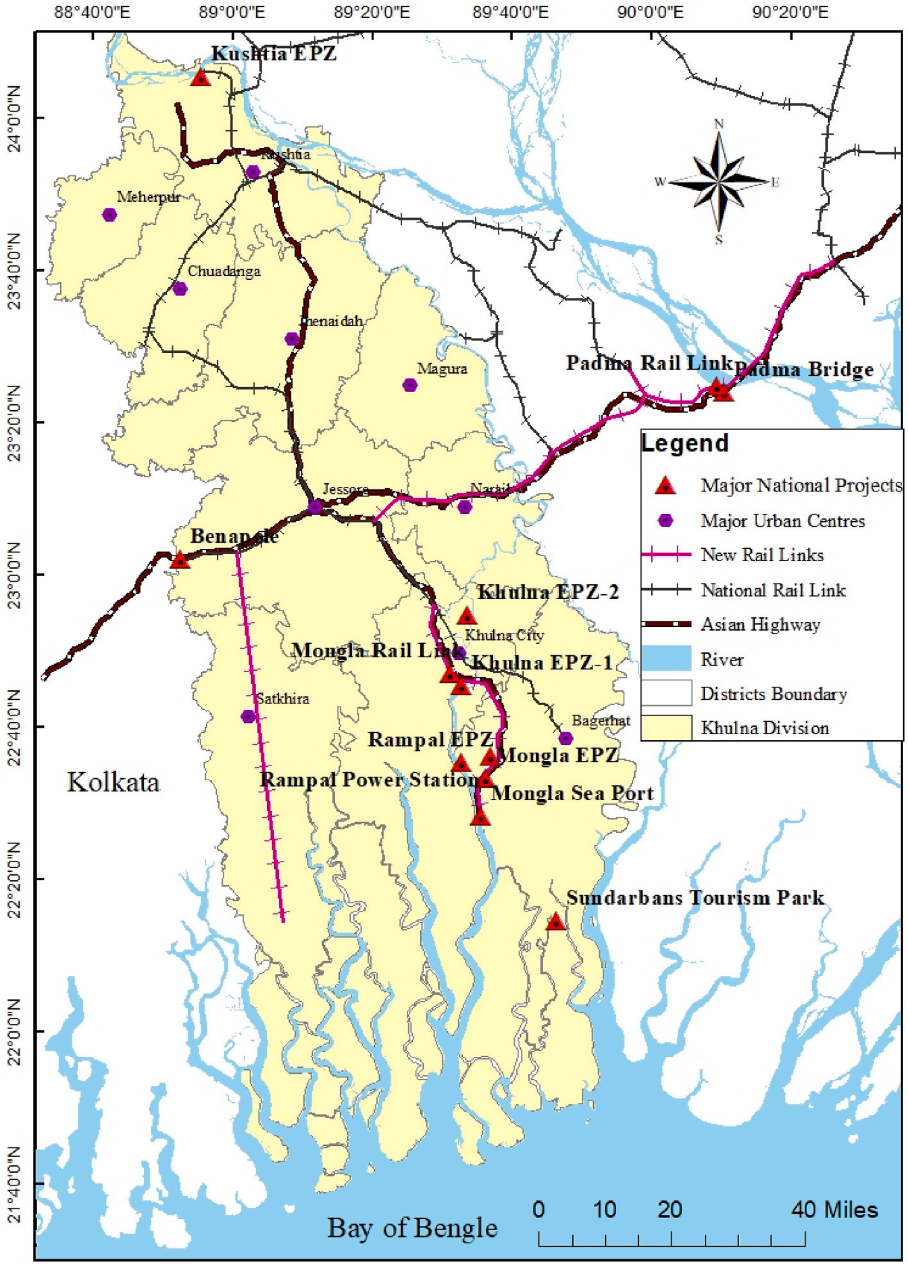

Fig. 2. Major infrastructure projects of Khulna region and its territory.

Table 1
Information of remote sensing data acquired from USGS.

Year	Satellite & Sensor	Pixel & Resolution	Spectral Resolution	Path & Row	Data Acquired	No. Of Image Tile
1990	Landsat 4–5 TM	30 × 30 Size pixel & 30 m resolution	Multispectral 7 Bands	137& 44	01/07/1990	2
				138 & 44	01/30/1990	
2000				137& 44	01/19/2000	2
				138 & 44	01/29/2000	
2010				137& 44	02/10/2010	2
				138 & 44	02/06/2010	
2020	Landsat 8 OLI/TIRS		Multispectral 11 Bands	138 & 44	01/17/2020	1

and spread canopy trees; (iv) built-up Area includes buildings, roads, houses, residential areas and all other hardscape elements. The accuracy of the image classification was measured using Kappa co-efficient, and overall accuracy, user accuracy and producer accuracy assessment. For accuracy measurement, 40 reference points against a single image class have been collected. 160 reference points for four categories have been selected at random. Both the development of confusion matrix to validate the raster images and ground truth cross validation have been done using Google Earth Pro.

$$\text{Kappa Co}-\text{efficient (T)} = \frac{(\text{TS} * \text{TCS}) - \int(\text{Column Total} * \text{Row Total})}{(\text{TS})2 - \int(\text{Column ToTal} * \text{Row Total})} * 100 \tag{1}$$

$$\text{Overall Accuracy} = \frac{\text{TCS}}{\text{TS}} * 100 \tag{2}$$

$$\text{User Accuracy} = \frac{\text{TCS of Water}}{\text{TS of Water}} * 100 \tag{3}$$

$$\text{Producer Accuracy} = \frac{\text{TCS}}{\text{Column Total}} * 100 \tag{4}$$

Here, TS = total sample and TCS = total sample with corrections boundary [45]. The result of the accuracy assessment of all segment for the four land use categories were above 80% (Table 2). In comparison to other studies, the result of the accuracy assessment is acceptable and fairly good, which contributed to the accurate analysis of urban expansion [33,46].

2.4. Urban expansion measurement

Spatial matrices are the widely used techniques to measure urban expansion. Based on the data availability, Annual Urban Expansion Rate (AUER), Urban Expansion Intensity Index (UEII), and Urban Expansion Differentiation Index (UEDI) have been used in this study. The Annual Urban Expansion Rate (AUER) measures the average annual rate of land development between two time periods. It is an altered version of the compound growth rate formula and is independent of spatial unit size.

$$\text{Annual Urban Expansion Rate (AUER)} = \left\{ \left(\frac{\text{BLA}_i^{t_2}}{\text{BLA}_i^{t_1}} \right)^{\frac{1}{t_2 - t_1}} - 1 \right\} \times 100 \tag{5}$$

BLA = Built-up area, i = the spatial unit, t_1 = the base year, and t_2 = the ending year. The result of the AUER represents the amount of change in the Built-up land area over time. There is no upper or lower limit [33].

The second is the Urban Expansion Intensity Index (UEII), which characterizes the degree of differentiation of urban expansion and illustrates the proportion of urban expansion of a spatial unit in relation to the total study area and study duration [29].

$$\text{Urban Expansion Intensity Index} = \left(\frac{\text{BLA}_i^{t_2} - \text{BLA}_i^{t_1}}{\text{TLAi} \times \triangle \text{t}} \right) \times 100 \tag{6}$$

Here, BLA = built-up land area; i = spatial unit; t_1 = base year; t_2 = ending year; $\triangle t = t_2 - t_1$, the difference of urban land at base year and ending year of spatial unit i; TLA = Total land area of the study area [32]. The UEII result depicts the urban expansion intensity of a spatial unit relative to the entire study area. The criterion for UEII value is as follows: greater than 1.92 indicates “high speed”; 1.92 to 1.05 indicates “fast”; 1.05 to 0.59 indicates “medium speed”; 0.59 to 0.28 indicates “low speed”; 0.28 to 0 indicates “slow”; and 0 to negative indicates “decreasing intensity” [47].

The Urban Expansion Differentiation Index (UEDI) is the third matrix that measures the disparity in land expansion between all spatial units. It is possible to use the index to assess regional urban land expansion and identify urban expansion hotspots. It compares the urban expansion of a spatial unit’s constituency to the urban expansion of the whole study area.

$$\text{Urban Expansion Differentiation Index} = \frac{\frac{|\text{BLA}_i^{t_2} - \text{BLA}_i^{t_1}|}{\text{BLA}_i^{t_1}}}{\frac{|\text{BLA}^{t_2} - \text{BLA}^{t_1}|}{\text{BLA}^{t_1}}} \tag{7}$$

Table 2
Accuracy assessment of image classification.

Year	1990 (%)		2000 (%)		2010 (%)		2020 (%)	
Category	User	Prod.	User	Prod.	User	Prod.	User	Prod.
Waterbody	98	85	93	95	100	93	93	95
Agriculture	90	90	95	76	93	93	100	85
Dense Vegetation	83	87	95	100	95	93	95	93
Built-up Land	80	89	80	97	85	94	80	97
Kappa Statistics	83		88		91		89	
Overall Accuracy	88		91		93		92	

Here, BLA_i is the built-up land area of the spatial unit, BLA is the built-up land area of the study area, i is the spatial unit, t_1 is the base year, and t_2 is the ending year. Greater than 1 indicates “fast growing area”; equal to 1 indicates “moderate growing area”; less than 1 indicates “slow growing area” and all negative values indicates “very slow growing area” [31].

The first spatial matric AUER measures annual urban growth with respect to a base year, the UEII measures the growth share of built-up area of a spatial unit with respect to both base year and whole study area and the UEDI measures the changes of built-up land of a spatial unit with respect to changes of built-up land of the whole study area.

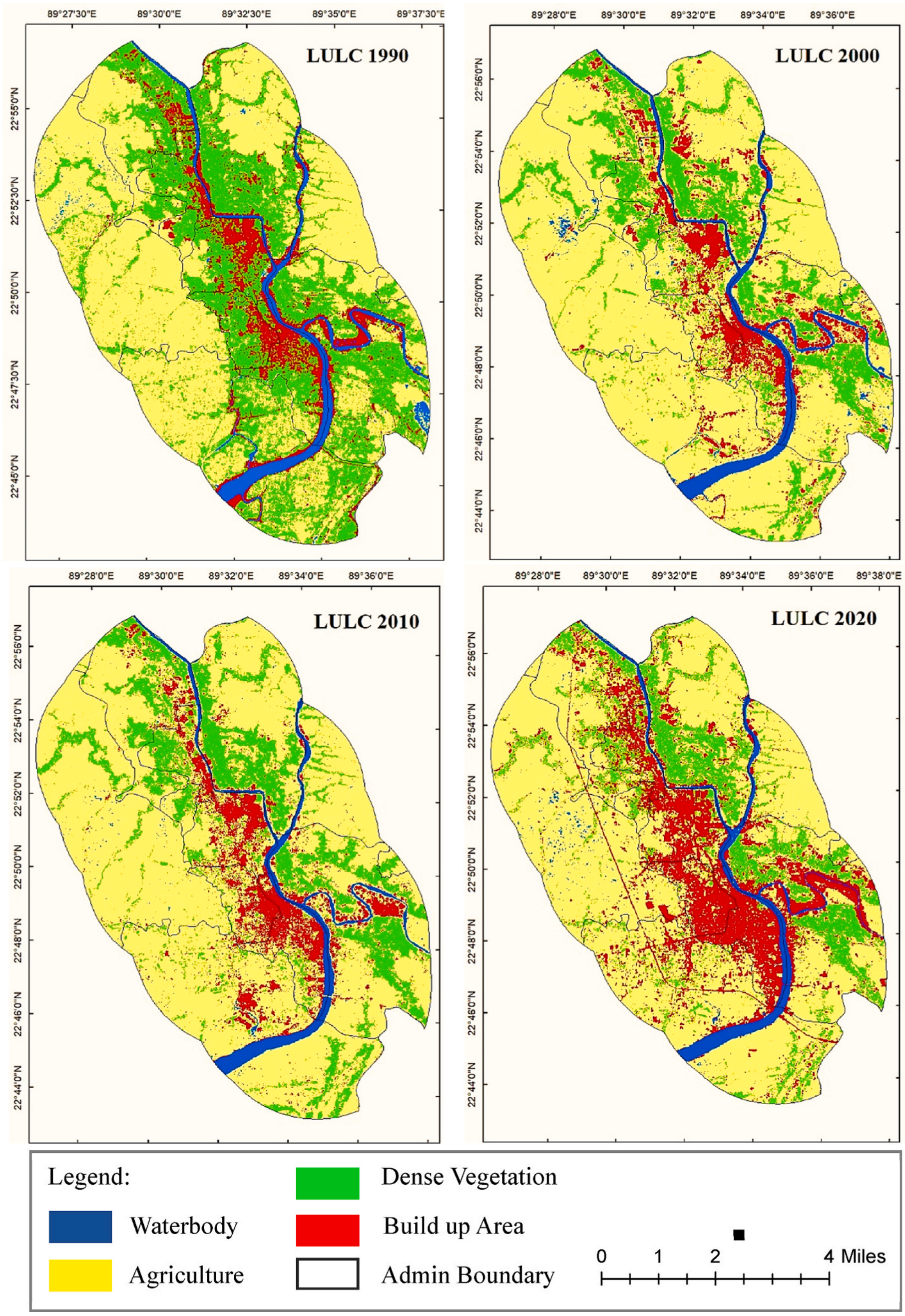

Fig. 3. Land use land cover map of the study area for 1990, 2000, 2010 and 2020.

3. Results

3.1. Changes in land use and land cover

From 1990 to 2000, dense vegetation has changed significantly more than other land uses. The previous decadal change in the land use land cover (LULC) map (Fig. 3) clearly indicates decrease in dense vegetation while other land uses including urban land use change are difficult to distinguish on the 1990 (top-left), 2000 (top-right), 2010 (bottom-left) and 2020 (bottom-right) maps. As a big portion of dense vegetation type is converted into different types of agricultural land use classes and built-up areas, that is the reason for increasing agricultural land use till 2010.

Built-up area has been increased from 1990 to 2000 but decreased in the northeastern side significantly in the map of 2010. In 2020, the built-up area grew substantially, absorbing a greater proportion of agriculture, dense vegetation and waterbody land uses in both the core and periphery (Fig. 3). From 1990 to 2020, the core city experienced infill urban expansion. Urban expansion followed a polycentric pattern in the periphery along the transportation corridor in the northwestern and southwestern regions. Due to the natural physical barrier created by the Rupsa River that plays the role of the breaking point of smooth transportation between city and north and northeastern part. For this reason, the intensity of urban development decreased in the north-eastern and northern area.

The decadal shift of land uses in the core (Fig. 4A) and periphery core (Fig. 4B) demonstrates that there has been no significant change in the waterbody during 1990–2020. Whereas the land use for agriculture has increased until 2010 and then decreased in 2020. From 1990 to 2000, built-up area increased, then decreased in 2010, again increased after 2010. In 2020, the entire study area experienced a leapfrog of built-up areas. In case of both core and periphery, dense vegetation type land uses have been continually decreased (Fig. 4A and B).

Urban land use appears to be increasing at the expense of dense vegetation. Although urban land use in the core area increased steadily during the first three decades, after 2010 the rate of urban expansion in the periphery exceeded that of the core (Fig. 5). In terms of urban expansion, both the core and the periphery experienced a leapfrog effect, but urbanization in the periphery increased even more than before.

3.2. Annual Urban Expansion Rate (AUER)

The annual rate of urban expansion of the study area was 0.45% from 1990 to 2000, 0.24% between 2000 and 2010, and 6.76% in 2020. All spatial units demonstrate a similar decline in urban growth after 2000, followed by a rebound after 2010. Even the most vibrant upazilas, such as Batiaghata, Dighalia, Dumuria, and Rupsa experienced a decline in urban growth rate between 2000 and 2010, from 0.96 to −0.94%, 1.97 to −3.35%, 2.95 to −4.86%, and 0.47 to 0.1%, respectively. Although Batiaghata, Khan Jahan Ali, Rupsa, Terokhada, and Dumuria had a negative growth rate, the urban growth rate increased between five to ten times greater after 2010 than it had been previously (Table 3). From 1990 to 2020, Khulna city's annual urban growth was incremental. There was a significant increase in built-up area of core till 2010 but that urban growth rate slowed after 2010 as it had reached a certain level of development. Another peripheral region, Dumuria, experienced declining urban growth after the year 2000 and accelerated after 2010 with highest growth rate at 31.43 and followed by Terokhada at 16.17, which was previously negative (Table 3).

The rise and fall of the AUER of the spatial units are depicted on a chart (Fig. 6) in which it is evident that in the first two decades, urban growth in the periphery was less than in the urban core. However, the peripheral upazilas experienced high urban growth rate from 2010 to 2020. According to the AUER, the potential spatial units for future rapid urban growth can be divided into four

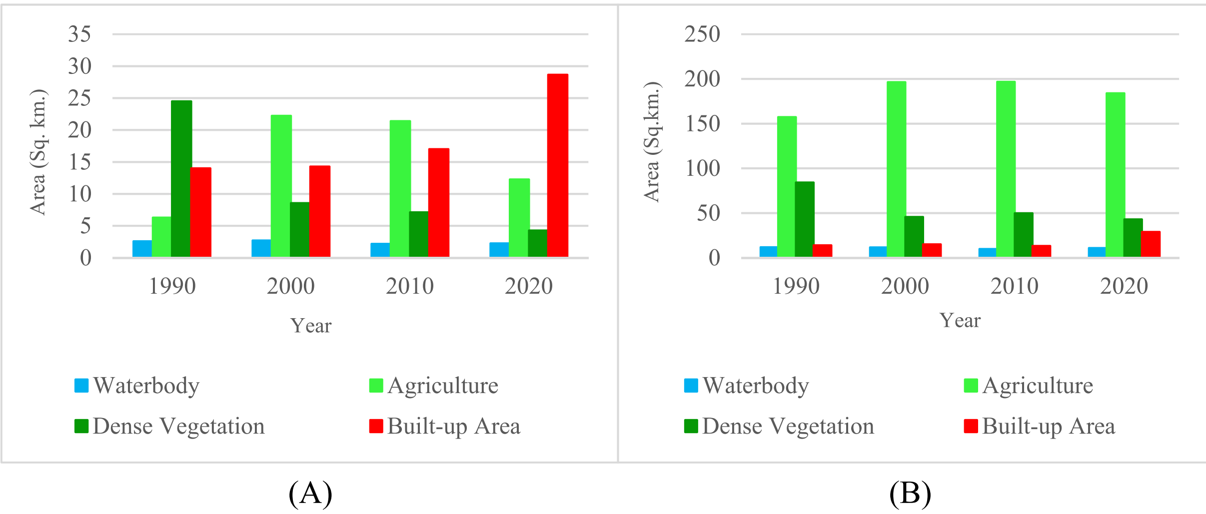

Fig. 4. Land cover area (km.) of land classes in Khulna city (A) and periphery (B).

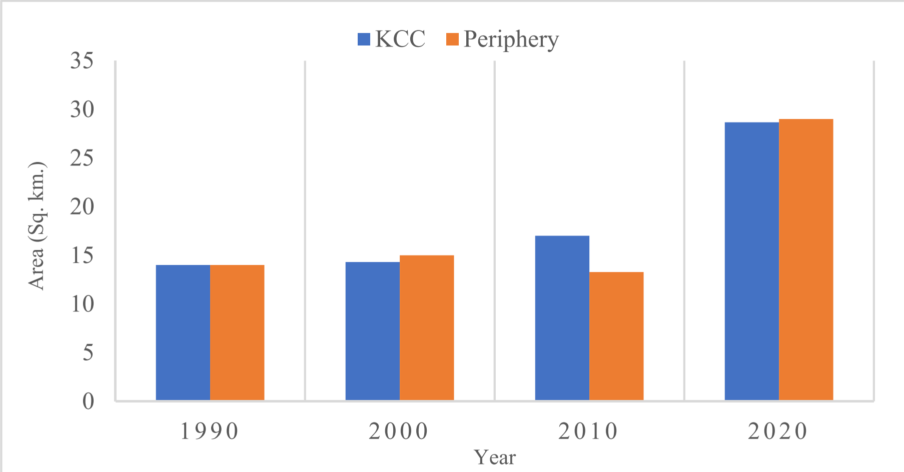

Fig. 5. Difference Between Built-up Areas of Core and 5 km. Periphery.

Table 3
Annual urban expansion rate of the study area.

	Built-up Land (km^2)				Annual Urban Expansion Rate (%)		
Spatial Units	1990	2000	2010	2020	1990–2000	2000–2010	2010–2020
Total Study Area	28.00	29.3	30	57.7	0.45	0.24	6.76
KCC	14.00	14.30	17	28.7	0.21	1.74	5.38
Batiaghata	3.21	3.53	3.21	7	0.96	−0.94	8.11
Dighalia	2.54	3.08	2.19	3	1.97	−3.35	3.17
Dumuria	0.24	0.32	0.20	3	2.95	−4.86	31.43
Khan Jahan Ali	2.16	1.92	1.70	4	−1.17	−1.19	8.92
Rupsa	5.43	5.69	5.75	11	0.47	0.1	6.7
Terokhada	0.56	0.45	0.22	1	−2.16	−6.73	16.17

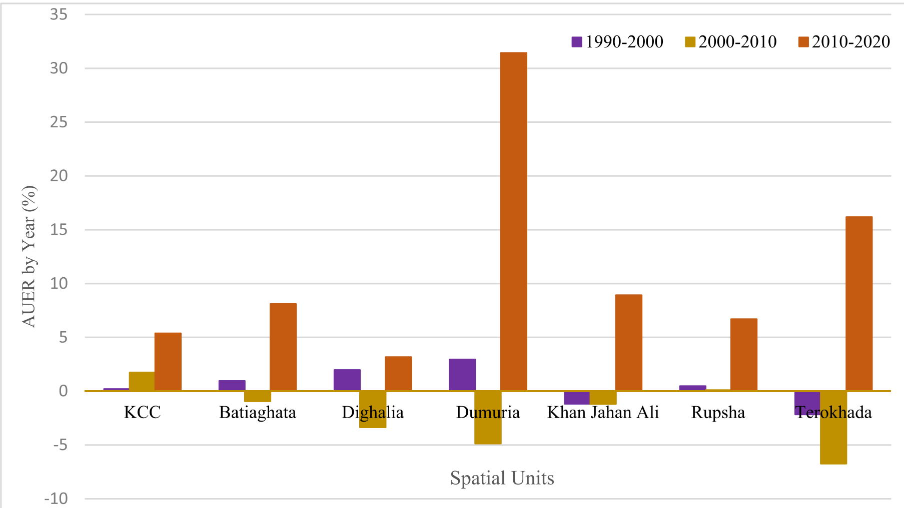

Fig. 6. Annual urban expansion rate of the KCC and peripheral areas.

categories: (i) Dumuria, (ii) Terokhada, (iii) Khan Jahan Ali and Batiaghata, (iv) Rupsa, KCC and Dighalia.

3.3. Urban Expansion Intensity Index (UEII)

Over the course of 30 years, the city of Khulna experienced intensifying infill types of urban expansion, while urban growth in the peripheral areas was interrupted. From 2000 to 2010, the value of UEII decreased or was negative. After 2010, both the core and periphery regions experienced an increase in urban growth. However, between 1990 and 2000 (first panel), Dighalia had a UEII value of 0.130 which is greater than the value of KCC. But between 2000 and 2010 (second panel), Dighalia's urban expansion intensity decreased. Until 2010 KCC had a low rate of urban expansion intensity with a UEII value of 0.57, but in 2020 (third panel) the urban growth rate increased with a UEII value of 2.463, which is the highest among others (Table 4). Khan Jahan Ali and Rupsa were classified as having a medium urban expansion intensity with UEII values of 0.82 and 1.00 respectively. Batiaghata and Dumuria experienced low speed urban growth intensity with respective UEII values of 0.58 and 0.47 (Table 4). According to UEII, Terokhada and Dighalia experienced minimal urban growth between 1990 and 2020. According to the UEII's findings, the potential urban growth hotspots include KCC, Khan Jahan Ali, and Rupsa (Fig. 7).

3.4. Urban Expansion Differentiation Index (UEDI)

The UEDI result indicates that Dumuria experienced rapid urban expansion between 1990 and 2000, with the highest UEDI value of 7.26. Dighalia and Batiaghata also grew rapidly between 1990 and 2000 with UEDI values of 4.64 and 2.10 respectively (Fig. 8, first panel). With a UEDI value of 1.03, Rupsa experienced slow urban expansion (Table 3). With a UEDI value of 0.46, KCC experienced less urban expansion than Khan Jahan Ali and Terokhada, both of which have negative UEDI values.

After the year 2000, KCC experienced a jump from 0.46 to 7.90 on the UEDI (, whereas other surrounding areas experienced a decline in urban expansion characteristics (Table 4). In this time duration, KCC experienced rapid infill urban growth which slowed down after 2010 (Fig. 8, second panel). After the formation of an urban core the rate of growth accelerates for a time and after a certain point, the potential for further growth decreases. For this reason, after 2010 KCC's urban growth slowed. After 2010, with the exception of Rupsa all peripheral spatial units including Batiaghata, Khan Jahan Ali, and Terokhada experienced rapid urbanization while KCC and Dighalia experienced only moderate urbanization. According to the UEDI, potential urban hotspots are Dumuria, Terokhada, Khan Jahan Ali, and Batiaghata (Fig. 8, third panel).

In general, Khulna experienced high urban expansion during the 90's; however, the trend slowed down in 2010. After 2010 the peripheral urban expansion was again more than the core. Here AUER and UEDI indices measure built-up land area change with respect to base year's built-up area and study area's built-up area, which represents the same results about the peripheral growth. However, UEII measures the built-up land use changes based on the total land area which shows different result from AUER and UEDI (Table 5).

Even though all the three indices do not result the same; however, they have revealed some common results. According to AUER and UEII, Dumuria is ranked first for potential urban development. In contrast, UEII showed that KCC has the most potential for urban growth. Urban expansion intensity of Khan Jahan Ali and Rupsa is fast as they ranked second in UEII and UEDI; however, their annual growth is slow. Batiaghata represents a moderate annual urban growth and urban expansion intensity according to all three indices (Table 6). KCC showed less potential for annual urban growth and urban expansion in terms of whole study area's built-up area, as it is already much developed. Dighalia is showed slow urban development intensity in terms of all the matrices. Terokhada is showed a high potential for urban growth in AUER and UEDI which are actually not in the real scenarios. They are both over the natural physical barrier of the Vairab river, which separates Dighalia and Terokhada from the core as direct transportation to core is absent.

4. Discussion

The results of LULC indicate that in the urban core, the amount of waterbody and agricultural land use increased between 1990 and 2000, but decreased after 2000. In the periphery, agriculture land use increased until 2010. All kinds of low dense vegetation are included in agricultural land class. These inclusions ultimately increased the amount of agriculture land class till 2010 and decreased in 2020 due to massive urbanization. In contrast, dense vegetation decreased significantly and was converted into agriculture [36,45]. Built-up land use has been increasing more than core area during 1990–2000. Due to the declining industrial sector and depopulation process for lack of employment from 2000 to 2010, the urban growth of the periphery was negative but the core area experienced infill urban expansion. After 2010, built-up land use of periphery has been doubling than core area. There is a diverse reason that triggered this rapid suburbanization process in the periphery.

Firstly, good transportation system development, port establishment and numerous projects undertaken by city authority is the reason of polycentric urban expansion of Khulna city. Establishment of Mongla Port in 2015, the Khulna-Jessore bypass road in 2008, and the Khulna-Mongla Rail link in 2016 have paved the way for export and import with India. Three secondary roads over Khan Jahan Ali, Dumuria, and Batiaghata connect this city bypass [27,48]. Thus, following the transportation network development, Khulna city followed polycentric expansion on north-western hinterlands. Under the policy framework for sustainable transportation development, Khulna Development Authority (KDA) undertook multiple projects to develop the inner and outer city transport system. Road redevelopment and widening to improve connectivity in the West, bus and truck terminal and overpass in northern direction, and development of bypass connecting the nearer satellite cities and seaport in west direction are attracting future developments [43].

Secondly, the availability of rich agriculture hinterland and cheap land price playing as a key factor where developments and land speculation for future development are placing. North-western hinterland and adjunct to the city without any natural physical barrier has availability of agricultural land. Thus, cheap land price and good transport network to the city is attracting residential, industrial and commercial developments in the urban fringe. Therefore, people of high and middle-income groups are buying land for speculative purposes and destroying valuable agricultural land [49]. Local community is also interested in converting agricultural land into residential properties and selling the land to developers or industrialists at good price and migrating to the city [50,44].

Table 4
Urban expansion intensity index and urban expansion differentiation index.

	Urban Expansion Intensity Index			Urban Expansion Differentiation Index		
Spatial Unit	1990–2000	2000–2010	2010–2020	1990–2000	2000–2010	2010–2020
KCC	0.063	0.570	2.463	0.46	7.90	0.75
Batiaghata	0.049	−0.005	0.580	2.15	−3.76	1.28
Dighalia	0.130	−0.00002	0.19	4.64	−2.08	0.40
Dumuria	0.013	−0.000002	0.47	7.26	−16.42	15.58
Khan Jahan Ali	−0.085	−0.08	0.82	−2.39	−4.72	1.46
Rupsa	0.049	0.01	1.00	1.03	0.42	0.99
Terokhada	−0.056	−0.11	0.39	−4.23	−21.00	3.77

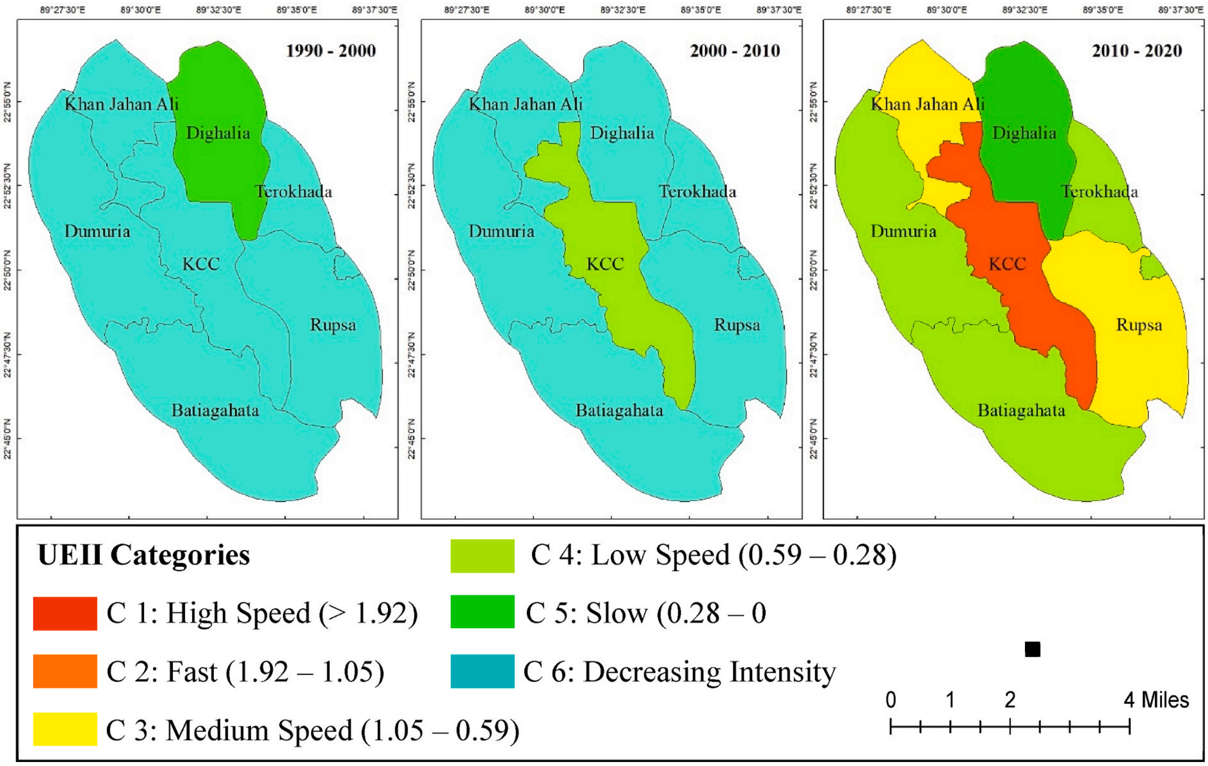

Fig. 7. Urban expansion intensity index of the study area for 1990–2000, 2000–2010 and 2010–2020.

The third most important reason is revitalization of industries and establishment of new industries that influence the urban expansion of both core and peripheral areas. The jute industries of Khulna city have endured several political regimes that have harmed the jute sector. In 2010, the government of Bangladesh, under a new policy regime, attempted to revitalize the industrial sector in the Khulna region through public-private partnerships, which played a significant role in the urban growth rebound after 2010. Restoration of the degraded industrial sector and the establishment of new industries in urban fringe areas after 2017 are creating employment opportunities [22] which attracts the disaster and poverty affected migrant people to move to the urban fringe or use it as a dormitory. Migrant people prefer north-western and south-western urban fringe near the working location where most of the industries and EPZs are located [51,52].

Among the three matrices, AUER and UEDI show relatively realistic result. These matrices are independent of the spatial unit's area. UEII measures the change of built-up land with respect to the whole study area where other land uses and spatial area is variable. Difference in the ratio of spatial unit area and total study area created an ununiformed platform to measure urban expansion. Most of the expansion of Khulna is occurring in the North, north-western and south-west peripheries as Rupsa, Batiaghata, Dumuria, and Khan Jahan Ali have cheap available lands and potential drivers to suburbanization. For this reason, these are identified as hotspots for future urban development. In addition, similar to other mid-sized cities, urban dynamics and the expansion pattern of Khulna is also following a clear polycentric pattern along the transportation network.

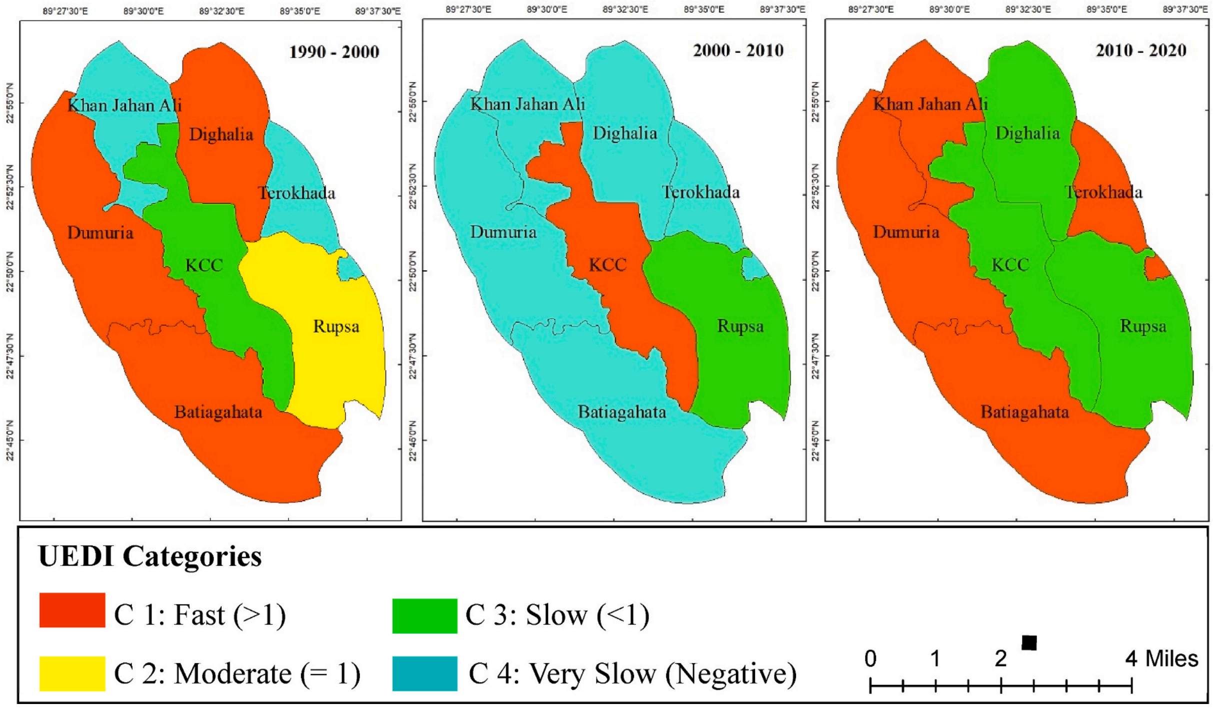

Fig. 8. Urban expansion differentiation index of the study area for 1990–2000, 2000–2010 and 2010–2020.

Table 5
Comparison of Urban Expansion Pattern of Khulna city and Surroundings.

	AUER (%)	UEII	UEDI	AUER (%)	UEII	UEDI	AUER (%)	UEII	UEDI
	1990–2000			2000–2010			2010–2020		
KCC	0.21	0.063	0.46	1.74	0.57	7.9	5.38	2.463	0.75
Surroundings	0.69	0.037	1.54	−1.21	−0.06	−4.8	8.12	0.59	1.28

Table 6
Urban hotspot according to the three indices.

Category	AUER	UEII	UEDI
1	Dumuria	KCC	Dumuria
2	Terokhada	Khan Jahan Ali, Rupsa	Khan Jahan Ali, Batiaghata, Terokhada, Rupsa,
3	Batiaghata, Khan Jahan Ali	Batiaghata, Dumuria	Dighalia, KCC
4	KCC, Dighalia, Rupsa	Dighalia, Terokhada	–

5. Conclusion

Using Landsat 4 & 5 images for 1990, 2000, and 2010, as well as Landsat 8 images for 2020, this study has quantified, analyzed and compared urban expansion in the core and urban fringe areas. Annual Urban Expansion Rate (AUER), Urban Expansion Intensity Index (UEII), and Urban Expansion Differentiation Index (UEDI) are the three urban growth indicators of area matrices used to measure the pattern and direction of urban expansion in the core and the periphery. For statistical calculations, the study employs open-access remote sensing data from the Landsat satellite, GIS, and Excel.

The study discovered that the peripheral area has been experiencing more expansion than core and it is expected to expand even faster than core. Built-up area has been increased in expense of dense vegetation. After 2010, the decrease in agricultural land class happened due to land speculation and suburbanization. In contrast, there is no significant change of waterbodies in both core and periphery throughout the study period. Transboundary and intra-regional transportation, economic corridor Mongla sea port and rail link, Rupsa, Batiaghata, Dumuria, and Khan Jahan Ali have a substantial incentive for urban growth. Direct and easy network connection between the core and the periphery is the primary factor that drives people to reside in the urban fringe, where living expenses, house rents and land prices are low. Due to the high cost of living in the city's core, low-income migrants reside in the surrounding upazilas. In Batiaghata, Dumuria, Khan Jahan Ali, and Rupsa, real estate development in the peripheral upazilas have additional impetus for urbanization.

If we generalize the result of the three matrices, AUER and UEDI represents almost realistic result for most of the spatial units like KCC, Batiaghata, Rupsa, Dumuria, Khan Jahan Ali. However, in some cases, Terokhada and Dighalia shows some outlier result due to image classification with low resolution. Taking into account all the practical scenarios and metrices, Dumuria, Batiaghata, Rupsa, and Khan Jahan Ali have been identified as future development hotspots. In addition, similar to other developed country's urban dynamics, Khulna city is also following polycentric pattern of urban expansion in the periphery. Though this study analyzed the urban growth of Khulna city, however, has scope for measuring urban expansion patterns of cities and their drivers of urban redistribution.

Authors statement

Irtija Alam: Conceived and designed experiments; Performed the experiments. Kamrun Nahar: Contributed reagents, materials, and analysis tools or data. Md. Manjur Morshed: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no competing interests.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.heliyon.2023.e13193.

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