Transformation towards a mega-regional formation of Khulna city, Bangladesh

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Abstract A mega-industrial region is frequently the result of purposeful regional development policies. Mega-region development is a new form of rapid urbanization and economic growth that is stimulated by government infrastructure projects. The objective of this research is to examine how the core built-up area and population growth of Khulna city, Bangladesh are slowing relative to the periphery as a result of mega-regionalization. We describe the spatial transformation of the city using GIS and remote sensing for built-up area identification and two urban expansion indices–expansion intensity index and urban expansion differentiation index–for quantitative measurements. The findings indicate that the city's periphery is seeing a higher rate of land use change and population agglomeration than the core. Secondly, the development hotspots are located in the peripheral regions. This change is largely fuelled by conventional speculative land and housing development similar to most cities with growing economies, and not the result of becoming a mega-industrial region. The land use transformation at the regional level and the city's periphery has catastrophic repercussions because of massive resettlement and depeasantization.

Keywords Urban restructuring · Regional planning · Geographic information system · Shrinking cities · Bangladesh

1 Introduction

Shrinking cities might be a new phenomenon for countries of the global South. Whether a city is expanding or shrinking can be determined by its three primary functions: a center of gathering, transport, and commerce [1]. Cities have historically benefited from their hinterland areas due to their pivotal position in the aforementioned three functions. The failure of shrinking cities to attract mobile capital for investment weakens their economic bases and results in capital outflows [2]. The literature on shrinking core areas and subsequent city regeneration documents it predominantly as a western country phenomenon resulting from suburbanization, deindustrialization and an aging population [3]. However, there is little understanding of how shrinking cities might be phenomena for the global south.

It is anticipated that the bulk of relatively new megacities will be located in the global south [4]. In addition, the number of cities with 1 to 5 million population (or secondary cities) nearly doubled between 1990 and 2018 [5]. These statistics grossly underestimate the underlying geographical growth dynamics of urban areas. Roughly defined administrative boundaries are an inadequate indicator of both spatial expansion and population distribution, resulting in

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a significant misrepresentation of metropolitan areas [4]. Several earlier studies identify urban expansion via peripheral (informal) sub-division [6] and new town development for the upper-income class as a form of social segregation [7, 8]. Recent research (e.g., [9] identifies socioeconomic characteristics and proximity to megacities as the primary drivers of city region expansion.

Aguilár & Ward [10] identified three primary transformation phases in their thorough examination of mega-city transformation. First, the integration of megacities into a global network of cities and their transformation into command and control centers for production and finance rather than production centers [11]. Second, due to the globalization of economic processes and information flows, the physical, cultural, and economic structure of the megacities of the global south will resemble that of the "world cities" or "global cities" of the global north [12, 13]. Thirdly, the urban growth rates of megacities continue to decelerate, while nearby and peripheral municipalities experience rapid growth, transforming them into polycentric city region structures. Thus, a complex megalopolis has resulted from a diffused urban growth, which encompasses peripheral towns and metropolitan centers.

As mega-regions differ in spatial and socio-economical characteristics, there is no universal theory to describe the transformation and restructuring processes [10], and it cannot be regarded as a continuation of the North Atlantic urban transformation process [14]. However, no study to our knowledge indicates the trend of secondary city's shrinking core in the global south. Our discussion is predicated on a clear distinction between secondary and subordinate cities. By secondary city, we refer to urban areas beyond the primate city region's influence, despite the fact that its command and control functions cannot be ignored. By subordinate cities, we refer to urban agglomerations located within vast mega-regions, i.e. a polycentric mega-city structure (see for example, [10, 15]).

In this research, we describe the case of Khulna, the third largest secondary urban agglomeration in Bangladesh. The city is in the process of becoming a mega-region, mostly as a result of various government infrastructure investment initiatives. We investigate how regional infrastructure initiatives are meant to build a spatially interconnected polycentric regional structure, in which Khulna will serve as a command and control center and become a global city. The real scientific contribution of the research is that it explains the transformation process of the secondary city of a developing country, Bangladesh. The country is striving for rapid urbanization as well as economic development. In this process, how government-led infrastructure can play a pivotal role in expanding the peri-urban areas, and consequently, shrink the core urban areas is the subject matter of this research. We refrain from predicting the success or failure of the mega-region formation and focus on the transformation of the city's built-up area.

The purpose of this study is to determine how peripheral land is being transformed in comparison to urban cores. In doing so, we determine whether the built-up area increase in the periphery suffices the urban core, so providing an early indication that the core city is shrinking. In general, there are three types of urban expansion: infilling, expanding, and outlying [16]. The term 'infilling' refers to the intensification of the current urban region, whereas 'expanding' typically refers to peri-urbanization and lateral physical development, frequently in the form of urban sprawl that encompasses adjacent small urban agglomerations. The term "outlying" refers to the formation of a new urban entity that is connected (through communication infrastructure) but administratively and spatially distinct from the mother metropolis. The peripheral areas of the cities of growing economies expand uncontrollably, and publicly available statistics are unreliable [9]. Geographic Information Systems and Remote Sensing provide a raster-based measure of land use and land cover change (LULC). We employ two distinct indices of urban land changes by focusing largely on built-up area development, which corresponds to the infilling and extending spatial transformation of Khulna city. The real contribution brought in by this research is that it explores the diversity of urban expansion of secondary cities of growing economies. Additionally, this research explains that cities of the global south might also follow the shrinking nature of the cities of the global north.

2 Literature review

Until the 1970s, it was believed that internal city structures were monocentric [17]. The monocentric urban model is conceptualized as a decreasing average urban density with distance from city centers, where residential regions surround employment and business centers located at the city's core. Typically referred to as the "core-periphery" paradigm, it represents an employment structure centered on manufacturing and material services. The increasing disintegration of monocentric city structure is a result of the expansion of transportation networks and the enhancement of communication technology. Low-cost transportation enables individuals to overcome spatial barriers, reorganizing urban economic activity and resulting in social and demographic dispersion from the urban core to economically beneficial nodes, i.e. suburbs and new towns [18].

Deng et al. [18] identified both centripetal and centrifugal forces of greater accessibility to transportation. The centripetal forces have agglomeration effects by raising the relative attractiveness of a particular urban region for households and businesses to locate [19]. Therefore, the urban population

grows as a result of the enhanced transport network, which expands opportunities for labor mobility and employment.

Second, increased mobility can disperse economic activities across several regions by means of an integrated and geographically interconnected infrastructure network. Through inter-sectoral spillovers across different industrial sectors [20, 21], a more balanced form of urbanization may develop. In China, interconnected polycentric urban agglomerations are actively promoted and regarded as a scientific urban layout. In reference to the Yangtze River Delta (YRD), Li & Wang [15] highlighted Beijing's role as the functional center of the YRD mega-region, where subordinate cities are woven into an internal network. These networked urbanizations are determined by historical and geographical circumstances. Lastly, an upgraded transport network might have a siphoning effect that can increase the relative desirability of areas, so dispersing economic activities over a region.

Thus, theoretical stretching indicates an approaching urban transition from monocentrism to polycentrism. Polycentricity merely refers to the presence of many competing centers of comparable importance inside a single metropolitan unit [22]. However, conceptualizing polycentricity is complex since it varies according to scale, i.e. intra-urban and inter-urban polycentricity. The majority (95 percent) of the world's cities are monocentric [23]. Additionally, a steady centrifugal expansion tendency was observed among the wealthier and more populous cities, as well as the cities with less expensive transportation and agricultural land. Different viewpoints on polycentricity have been examined, including labor productivity, industrial sub-urbanization and administrative decentralization [22].

One of the most significant effects of enhanced transport networks is the siphoning effect, which results in the contraction of large cities. 'Shrinking cities' is a metaphor for the demographic and economic decline of cities [24, 25]. Due to the inadequacy of population decline as an indicator of shrinking cities, and the lack of socio-economic data over constantly shifting urban administrative boundaries [18], alternative methods must be developed for measuring the spatio-temporal transformation of cities. We used satellite image analysis to measure the spatio-temporal transformation of the Khulna city region on a spatial scale. Additionally, we measure the distribution of population and built-up area increase at the city region scale.

3 Materials and methods

3.1 Study area

Khulna is one of Bangladesh's eight divisions (first tier administrative unit) (Fig. 1). As a divisional city, it serves as a regional and tertiary administrative, political, educational, and economic hub for ten districts (second tier administrative unit). The city provides economic prospects for people and serves as an engine for the hinterland's growth, a source of informal and seasonal employment, and a destination for climate migrants.

Successive governments have invested in transforming Khulna into an industrial center in order to capitalize on the city's advantageous geographical position. Jute and paper mills were the two largest industrial sectors, but they were unable to sustain industrial supremacy due to falling jute prices in the international market and a national economic shift toward the readymade garments and shrimp processing industries. In addition, governments aggressively subsidized the industries, which proved futile for their long-term viability. During the 1980s and 1990s, structural adjustment measures reduced government subsidies for the industrial sector, leading to massive layoffs and the closure of several jute companies [26].

Government-led stimulus projects involving infrastructure, export processing zones, utility facilities, power plants, tourism, and cross-border connectivity with India will have a significant impact on the city's future economy (Fig. 1 and Table 1). Modernization of Mongla port, reduced travel time to Dhaka via Padma Bridge, cross-border rail and road connectivity with Kolkata, India, and connection with the Asian Highway, gas supply, and dedicated export processing zones–these are expected to provide an economic boost to the south-western region of the country, including Khulna city. Gopalgonj, the home district of Prime Minister Sheikh Hasina, is located at a crossroads, supporting the government's guarantee of investment in the region (Fig. 2).

The study area is comprised of Khulna city and its surrounding areas, totaling to 500.86 km² (Fig. 3). Poly-centers (e.g., satellite and dormitory towns) are often located 30–60 km from the metropolitan city limits [10]. Given the small size of the city, inclusion of neighboring upazilas (the third and lowest tier administrative unit) suffices to illustrate the peripheral suburbanization of Khulna. The area of the Khulna City Corporation is 50.61 km². The city consists of 31 wards and 200 villages with a total population of 663,342. The population of the Statistical Metropolitan Area (SMA) is 1.05 million [27]. The study contains eleven upazilas along with the city area. The city is situated at the junction of the Rupsha and Vairab rivers and is laid out along the Vairab.

3.2 Urban growth/shrinkage framework

Following Acheampong et al. [28], we employ two indices to compare urban expansion in the core versus the periphery from 1991 to 2001, 2001 to 2011, and 2011 to 2021. First, the urban expansion intensity index (UEII) is computed for the built-up area (Eq. 1).
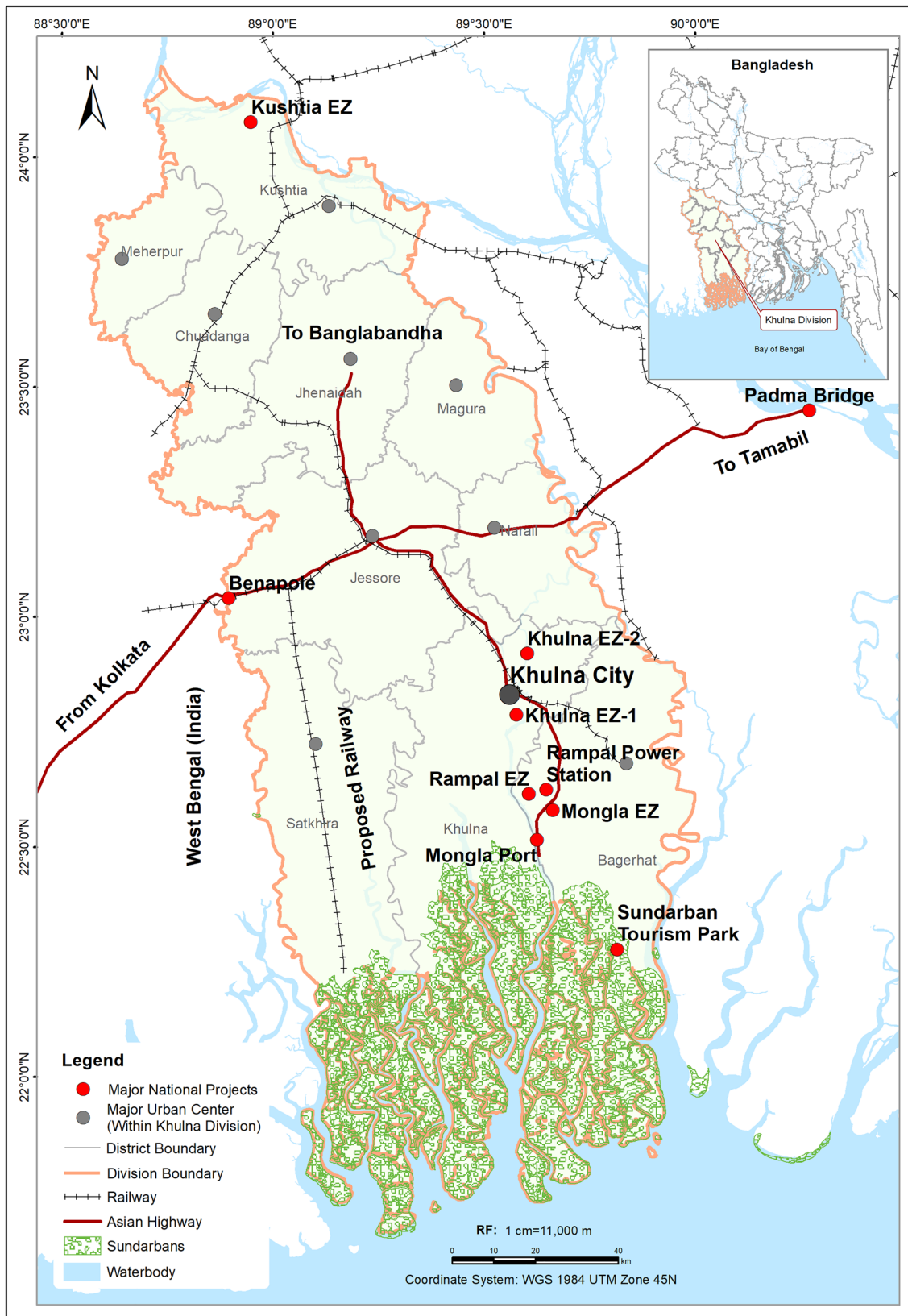
Fig. 1 Khulna city region and infrastructure projects (Source: Adapted from BEZA, 2020 and Authors, 2022)

Table 1 Economic zones and mega projects near Khulna city

Export processing zones			Government mega-projects
Name	District	Area (acre)	Mongla Port modernization
Mongla EZ	Bagerhat	205	Padma bridge
Mongla EZ*	Bagerhat	110.15	Khulna railway station expansion and connectivity with Kolkata, India
Rampal EZ	Bagerhat	300	Khulna Gas distribution company
Sundarban tourism park	Bagerhat	1546.35	Dhaka Mongla rail network
Khulna EZ -1	Khulna	519.52	Khulna Water Supply Improvement project
Khulna EZ -2	Khulna	509.64	Rampal Coal Thermal Powerplant

*Government to government (G2G) for Indian investors (Source: BEZA, 2020)

$$UEII_i = \frac{ULA_i^{t_2} - ULA_i^{t_1}}{TLA_i \times \Delta t} \times 100 \qquad (1)$$

where $UEII_i$ is urban expansion intensity index of unit i; $ULA_i^{t_2}$ and $ULA_i^{t_1}$ are built-up area of a spatial unit i at time t_2 and t_1, respectively; TLA_i is the total area of the spatial unit; and Δt is the time lag between t_2 and t_1. UEII explains the extent of difference in built-up area, thus urbanization, and explains the growth as a percentage of the total area over a certain period [28, 29]. The standard for interpretation of the UEII values are as follows: value > 1.92 is "high"; between 1.05 and 1.92 is "fast"; between 0.59 and 1.05 is "medium"; between 0.28 and 0.59 is "low"; and between 0 and 0.28 is "slow" [30].

Urban expansion differentiation index is the second index (UEDI). It is the ratio of a given area's urban expansion rate to the urban expansion rate of the studied region (Eq. 2). UEDI is a comparative measure of urban expansion between different geographical units that is especially effective for analyzing regional urban development and measuring development hotspots [28].

$$UEDI_i = \frac{\left| ULA_i^{t_2} - ULA_i^{t_1} \right| \times ULA^{t_1}}{\left| ULA^{t_2} - ULA^{t_1} \right| \times ULA_i^{t_1}} \qquad (2)$$

where $UEDI_i$ is the urban expansion differentiation index of unit i; $ULA_i^{t_2}$ and $ULA_i^{t_1}$ indicate the built-up area of a spatial unit i in t_2 and t_1 period; $ULA_i^{t_2}$ and $ULA_i^{t_1}$ indicate the total built-up area of another spatial unit in t_2 and t_1 period. The UEDI has no standard value for categorization. Because the UEDI of the total area is always equal to 1, it serves as a development hotspot in the sub-region. The three possible interpretations of the UEDI values are: values > 1 for a constituent spatial unit (i.e., district) indicate "fast" growing areas or development hotspots; values = 1 indicate "medium" growth; and (3) values < 1 indicate "slow" growth.

3.3 Data

To investigate the spatiotemporal dynamics of urban regions, a set of satellite images spanning four decades (1991, 2001, 2011 and 2021) were collected. Land use/land cover (LULC) change was evaluated across the study area using Google Earth Engine images of pre-processed Landsat imagery. It provides online access to a USGS collection of archived Landsat data [47]. To avoid confusion regarding farmland and barren soil, or geographical expansion/reduction of water body area [31, 32], all satellite images were captured in the same month, between January 1 and January 31. The first three images (1991, 2001, and 2011) were extracted from the USGS Landsat 5 Surface Reflectance Tier 1 image collection of Google Earth Engine, while the 2021 image was extracted from the USGS Landsat 8 Surface Reflectance Tier 1 image collection. Each image has a spatial resolution of 30 m. The images with the least amount of cloud cover and atmospherically corrected sceneries were utilized as the major input data [32]. In addition, socioeconomic and administrative data on the Khulna city and its surrounding upazilas are compiled from Bangladesh Bureau of Statistics (BBS) and other secondary sources.

3.4 Image classification and accuracy assessments

The image classification process was done using the Google Earth Engine Java Script API. Thereafter, classified images were exported from Google Earth Engine. Then map composition and analysis were done in ArcGIS 10.8. Random Forest is one of the most extensively used LULC classification algorithms for having high accuracy even when applied to noisy datasets. Tamiminia et al. [33] reviewed 349 Google Earth Engine peer-reviewed articles over the last 10 years and showed that the Random Forest algorithm is the most
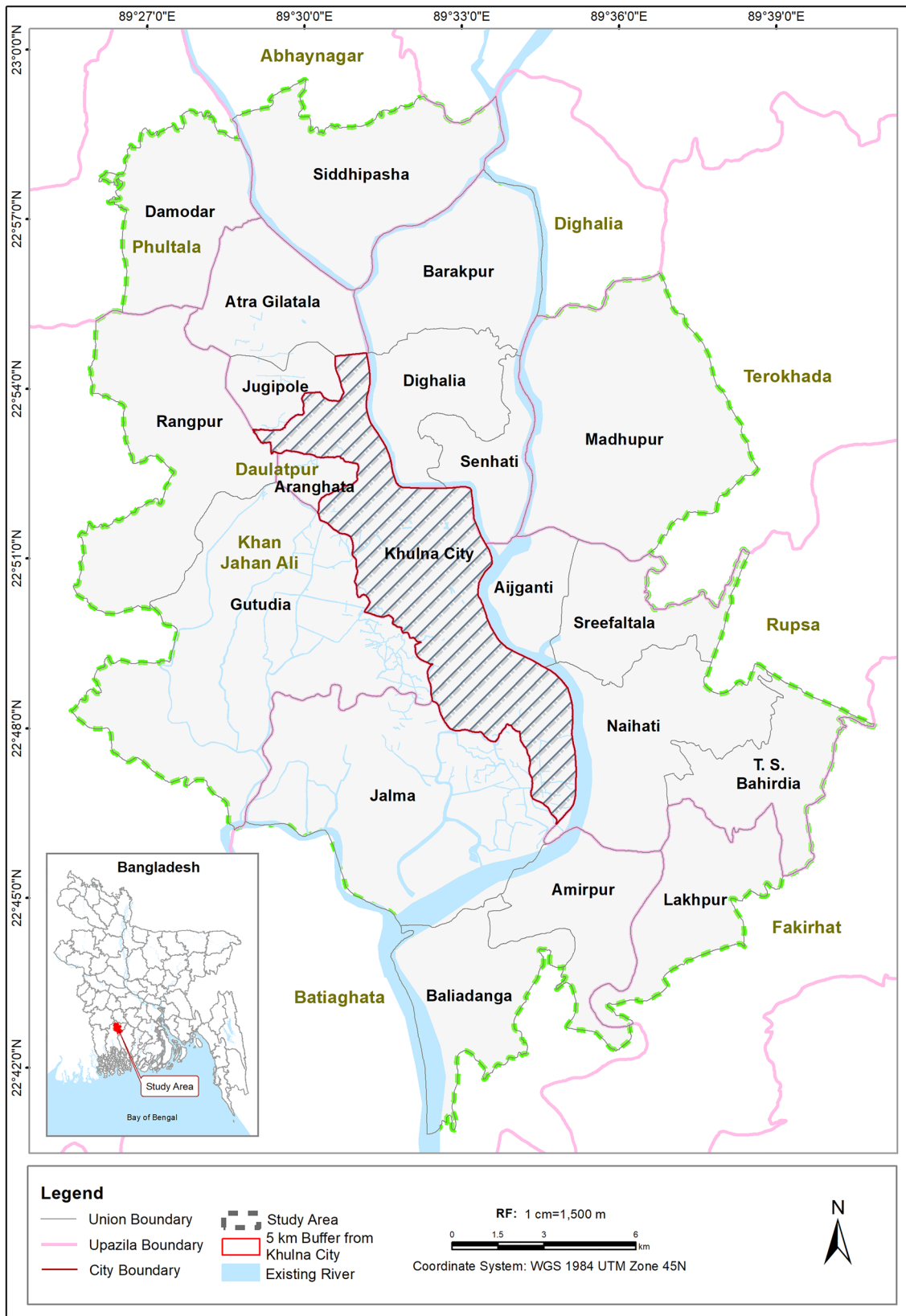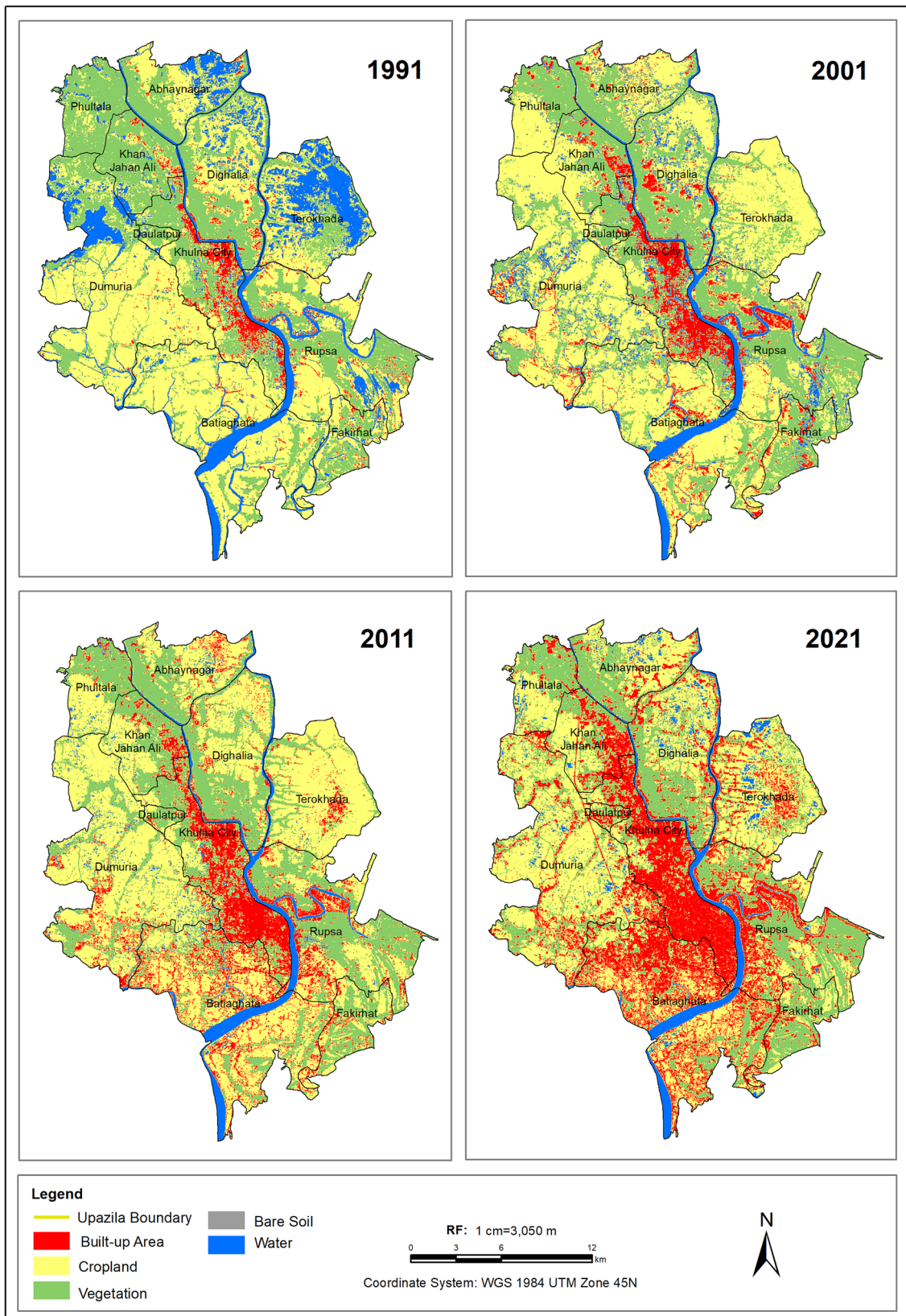
Fig. 2 Study area

Fig. 3 Decadal growth of built-up area of Khulna and its peripheral region

frequently used classification algorithm for satellite imagery. Based on the nature of our data and recommendations of previous studies, we selected 100 as the number of decision trees (ntree = 100), while mtry was set to the default value (square root of the total number of features).

More than 400 training points were created each year for supervised image classification and accuracy assessment. To train Random Forest, 70% of the data was used (a supervised classifier algorithm), and the remaining 30% of the training data was used for accuracy assessment [34]. Though our main focus is only the built-up area, five LULC classes were generated to get a better result. In five LULC classes, the built-up area includes all infrastructural areas like residential, commercial, transportation, industrial, etc. The overall accuracy of the LULC for 1991, 2001, 2011 and 2021 is 0.887, 0.885, 0.873 and 0.893, respectively. For a better understanding of the accuracy of LULC data, see the confusion matrix in Table 2 for 1991 and 2021. LULC data were exported from Google Earth Engine after accuracy assessment. The built-up area was then calculated, and respective maps were created.

4 Results

4.1 LULC

Figure 3 illustrates the decadal LULC for 1991, 2001, 2011 and 2021. The built-up areas have gradually expanded over time, both within the city and in its outskirts. However, built-up area expansion consolidated around the city's southern periphery and along the city's major road and rail facilities (Fig. 3). The city's eastern and northern peripheral regions experienced comparatively lower growth in built-up areas due to the natural barrier, i.e., the Vairab river.

Figure 4 compares the built-up area growth between the city and its peripheral region. Both the city and its peripheral regions exhibited a positive growth trend. However, while the city's growth pattern had been relatively stable, the peripheral urban regions expanded at a faster rate. Obviously, the scarcity of available land and the zoning regulations were the significant obstacles to the growth of the city's built-up region. The periphery displayed a trend of initial fragmentation followed by consolidation.

Table 2 Confusion matrix for LULC

LULC Class	1991							2021						
	1	2	3	4	5	UA	PA	1	2	3	4	5	UA	PA
Built-up area (1)	29	3	1	0	1	0.87	0.85	29	2	1	0	0	0.82	0.90
Cropland (2)	4	34	2	0	2	00.85	00.80	6	31	0	0	1	0.83	0.81
Vegetation (3)	0	1	32	0	0	0.91	0.96	0	1	31	0	0	0.96	0.96
Bare soil (4)	0	1	0	2	0	1	0.66	0	0	0	1	0	1	1
Water (5)	0	1	0	0	29	0.90	0.96	0	3	0	0	25	0.96	0.89
Overall accuracy	0.887							0.893						
Kappa statistics	0.850							0.857						

UA = User's Accuracy; PA = Producer's Accuracy

Fig. 4 Decadal growth of built-up area of Khulna and its peripheral region
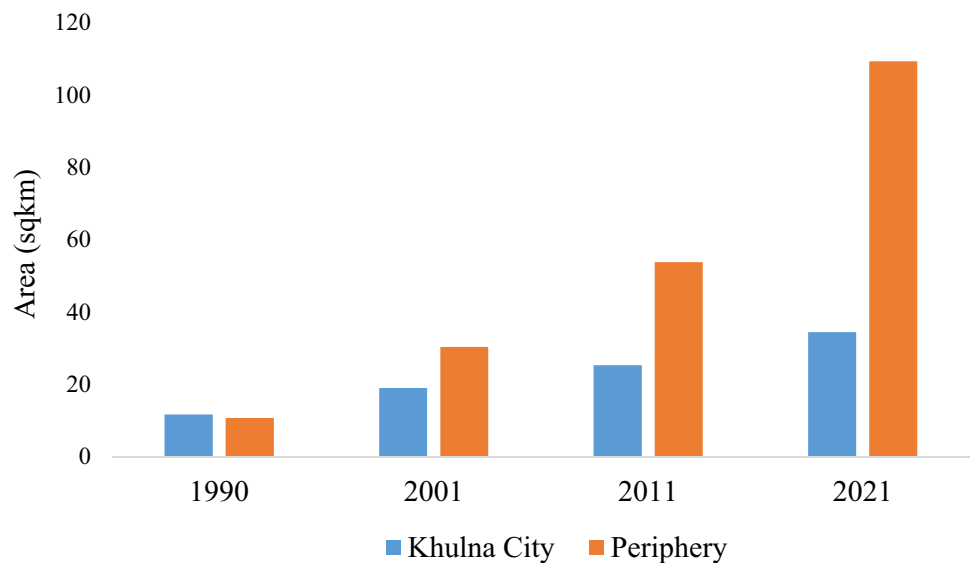
Among the peripheral areas, Batiaghata and Rupsha upazila had the highest built-up area growth, which was mostly due to the road connectivity (i.e., Khanjahan Ali Bridge connecting Khulna to Dhaka). The city's linear development trend was mostly due to its location along the Vairab river, which was also a natural barrier to peripheral expansion in the East (i.e., Terokhada and Dighalia).

4.2 Urban expansion intensity index (UEII) and urban expansion differentiation index (UEDI)

Between 1991 and 2001, Khulna city experienced "fast" (UEII = 1.64) built-up area expansion intensity (Table 3). This growth of built-up areas coincided with the formation of the Khulna City Corporation in 1991, along with the availability of public services and establishment of educational institutions i.e., Khulna University acted as an incentive for urban agglomeration. Only two peripheral upazilas had "medium" built-up area growth intensity and the rest of the peripheral areas had "slow" and "low" intensity. During the subsequent phase, between 2001 and 2011, Batiaghata upazila had "fast" UEII. However, between 2011 and 2021, five peripheral upazilas and Khulna city have "fast" UEII. Moreover, Daulatpur upazila had a higher intensity index (UEII = 3.07) than Khulna city (UEII = 2.04). The rest of the upazilas too had higher UEII than the years between 2001 and 2011.

The UEDI showed that the peripheral areas had higher built-up area growth than Khulna city (Fig. 5). The UEDI > 1 indicates "very fast" built-up area development. The UEDI showed no pattern of development among Khulna city and its surrounding upazilas; however, the south-western areas had a higher trend than the rest. Our analysis, however, did not consider the densification of built-up areas.

4.3 Population agglomeration

The Khulna division had a declining population growth trend compared to the overall Bangladesh trend. Moreover, Khulna district had a negative population growth rate between 2001 and 2021 (Fig. 6). At the same time period, Khulna city experienced a declining population growth trend. The population growth trend has shown a non-significant improvement between 2011 and 2021 (forecasted). On the contrary, the peripheral areas experienced a declining but positive population growth trend from 1991 to 2001 and 2001 to 2011 (no population forecast was available for 2021). Thus, the peripheral population growth trend was significantly higher compared to the city.

5 Discussion

Bangladesh is urbanizing rapidly in terms of population agglomeration. However, population growth rates for both Khulna city and Khulna district are negative (see Fig. 6). This is an indication that Khulna as a regional city is failing to attract population. This is, however, opposite to the peripheral population growth trend, where both the built-up area and the population growth trend are positive. Therefore, Khulna city indicates the opposite of the global growth tendency of cities with populations between 1 and 5 million [35]. The city's socio-economic status depicts a dire state. For example, unemployment (25.5%), underemployment (31.33%) and informal employment (48%) characterize the labor market [26, 36]. The incidence of poverty is around 28 percent, whereas the population below the extreme poverty line is approximately 15 percent [27, 37]. Finally, more than half of the total city population–including 520 slums

Table 3 Urban expansion intensity index and urban expansion differentiation index

Study area	Area	Built-up area (sq.km.)				Urban expansion intensity index					
		1991	2001	2011	2021	1991–2001	Remarks	2001–2011	Remarks	2011–2021	Remarks
Khulna City	44.87	11.6	18.96	25.24	34.39	1.64	Fast	1.4	Fast	2.04	Very Fast
Abhaynagar	32.31	0.42	1.58	2.69	3.54	0.36	Slow	0.34	Slow	0.26	Very slow
Batiaghata	90.67	1.11	6.2	17.94	37.69	0.56	Slow	1.29	Fast	2.18	Very fast
Daulatpur	3.24	0.02	0.21	0.32	1.31	0.58	Slow	0.34	Slow	3.07	Very fast
Dighalia	51.47	2.12	4.21	4.75	7.87	0.41	Slow	0.1	Very slow	0.61	Moderate
Dumuria	94.57	0.7	4.07	6.98	15.88	0.36	Slow	0.31	Slow	0.94	Moderate
Fakirhat	19.04	0.86	2.22	2.28	3.13	0.71	Moderate	0.03	Very slow	0.45	Slow
Khan Jahan Ali	24.43	1.06	3.01	3.33	8.06	0.8	Moderate	0.13	Very slow	1.94	Very fast
Phultala	21.19	0.05	0.67	1.11	2.31	0.29	Slow	0.2	Very slow	0.57	Slow
Rupsa	70.15	3.76	7.57	11.59	20.71	0.54	Slow	0.57	Slow	1.3	Fast
Terokhada	48.92	0.54	0.58	2.81	8.85	0.01	Very slow	0.46	Slow	1.23	Fast
Total	500.86	22.24	49.29	79.03	143.7						

Range: 0 -0.28 = Very slow; 0.28 -0.59 = Slow; 0.59–1.05 = Moderate; 1.05–1.92 = Fast; > 1.92 = Very fast
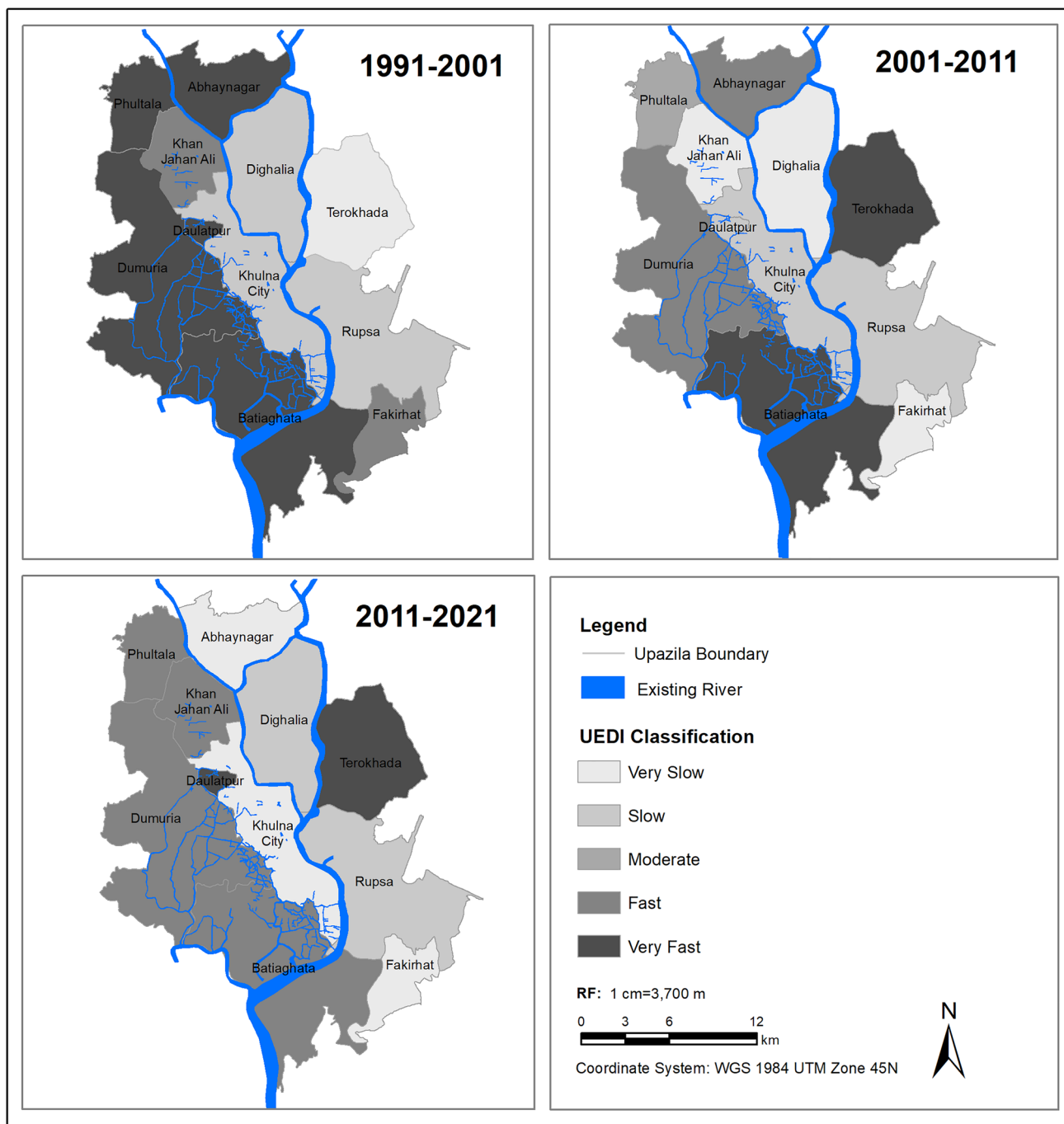
Fig. 5 Urban expansion differentiation index

of varying sizes and 5,080 settlements, totaling to 57,048 dwellings and 98,122 households [36]–live in poor communities. These numbers, which can be linked to the city's deteriorating economic status, provide a barrier to Khulna becoming a regional global city.

Globalization and related economic processes have transformed historical production centers into command and control centers [14]. However, Khulna has lost its historical character as a production hub, and the city now aspires to become a global city with command and control over subordinate metropolitan centers. The infrastructural and economic processing zone led development strategy, which is comparable to the YRD's urbanization strategy, is Khulna's attempt to capitalize on its historical and geographical advantages. Multiple infrastructural projects backed by EPZs suggest that Khulna will become the center of the

Fig. 6 Population growth rate of Khulna city and peripheral regions [27, 41]
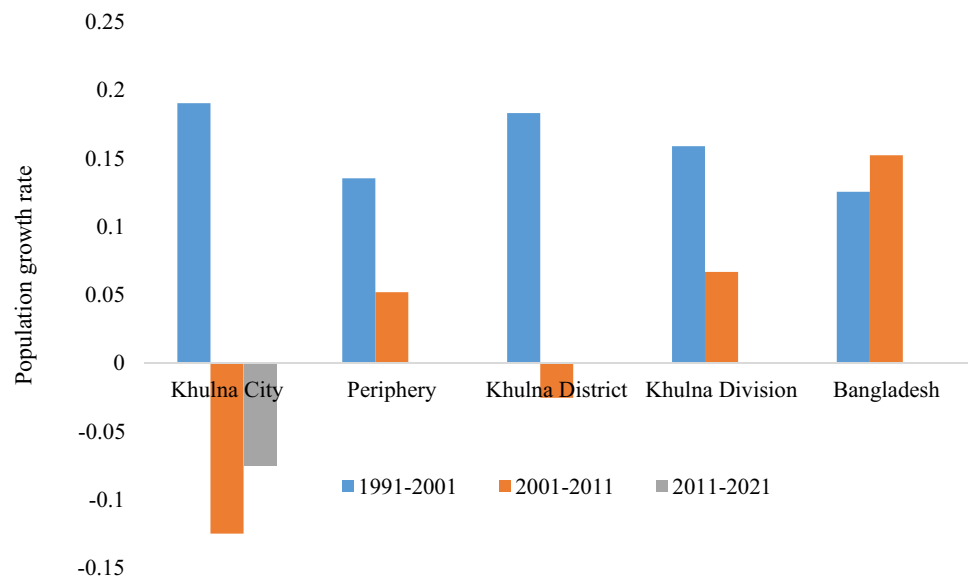
southwest region. This, however, hinges on the success of Khulna's economic revitalization in attracting investments.

Our data illustrates the slowing urban core and the spatial urban expansion in the periphery. Given that the population is declining in the city area (see Fig. 4), much of the urbanization in the periphery (Fig. 5) is speculative land and housing development. The 1993 National Housing Policy (updated in 2004 and 2008) marked a substantial change from the government's role as a housing supplier to facilitator of private sector land and housing supply [38]. Because of the susceptibility of peripheral areas to land and housing development [9], ecologically significant lowlands are being filled and a speculative land market is driving land conversion on the city's outskirts. Availability of cheap (and often agricultural) land is a pre-condition for private land and housing development, which is being reflected by the shifting urban expansion intensity index (UEII) and urban expansion differentiation index (UEDI). As a result, speculative subdivision can partially explain peripheral urban expansion.

The dark side of the infrastructure developments and economic zones (EPZs) is the rampant acquisition of private agricultural and low-land of ecological significance, leading to displacement and depeasantization of the local community. For instance, the Padma Multi-purpose Bridge has acquired 10.62 km^2 of land, affecting over 75,000 people in the districts of Madaripur, Munshiganj, and Shariatpur. Notably, 83 percent of the project-affected people that lost land are smallholders (own less than 33 decimal) [39]. The Rampal Power Plant has acquired 7.42 km^2 of predominantly shrimp ponds in the Rampal upazila of Bagerhat district [40]. In addition to the project-related land acquisitions, around 300 industrial agglomerations have acquired more than 40.47 km^2 of village land near the Rampal Power Plant.

While megaprojects are certain to promote economic growth and create jobs in the industrial sector, the expropriation of the agricultural poor and the loss of livelihoods due to mass eviction are frequently excluded from the development narrative.

6 Conclusion

This paper has presented the slowing core city built-up area against the expanding peripheral region of Khulna city, Bangladesh. Two indices—the urban expansion intensity index and the urban expansion differentiation index—are used to quantitatively measure the contrast between the core and peripheral built-up areas. Subsequently, the difference in population agglomeration between the core and peripheral regions is compared. The key finding is that the peripheral areas are gaining more built-up areas than the core city area. Secondly, Khulna is at a very early stage of becoming the center of a mega-region. The case is presented from the perspective of a mega-region concept where Khulna is showing early signs of shrinking city and is in the process of becoming a center of command and control of the subsidiary urban production centers. Several interpretations can be made from the study. First, the government's infrastructure-led regional development is a strategy for both the mega-region and the revitalization of Khulna city. In this process, Khulna is expected to become the center of a polycentric mega-region. The provision of public infrastructure is a catalyst for peripheral speculative land conversion, a transition to a sprawling mega-city rather than a functionally compact one. Unprecedented land conversion, which is constantly shifting in pursuit of inexpensive land, and population clustering in

the periphery regions are indicators of a geographically megacity. As the city's economy flourishes, the periphery is anticipated to become denser. Depending on Khulna's success in becoming a global city, a discourse is needed to address the trade-offs between rapid industrialization and land acquisition/resettlement.

The limitation of this study is the use of Landsat images with low spatial resolution. High-resolution images, such as data from Sentinel-2, can certainly enhance the classification accuracy. However, high-resolution images for the years 1991 and 2001 are not freely available. It is often advised to use images of the same sensor and resolution for a comparative work. We, therefore, used Landsat data. Secondly, the non-random collection of field training data (thus introducing spatial bias) is due to budget constraints. Finally, defining peripheral areas is difficult as urban expansion may follow major arterial roads.

Author's contribution MMM (corresponding author) was responsible for the idea, writing and organisation, making final draft and submitting the paper. TM and SKS prepared the maps and was responsible for data collection. FYS and AKI were responsible for field work and data analysis. SS was responsible for editing, and grammar and fact check.

Declarations

Conflict of interest The Authors declare no conflict of interests. All information sources are cited and referenced accordingly.

Human and animal rights This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

Ethical approval This is to confirm that the paper "Slowing core city growth and expanding peripheral region: towards a mega-regional formation of Khulna city, Bangladesh" has been submitted to Spatial Information Research by the following ethical issues: The manuscript has submitted only in this journal and not published in any language before. All the data (primary and secondary) and results (image, graph, and table) used here was not manipulated. All the data, text, or theories by others used here have sufficiently are being acknowledged and referenced. All authors have consented to submission and publication in Spatial Information Research. The authors' affiliation institution is aware about this research and publication, and the research work was done under the direct supervision of the institution. This research does not deal with any human and animal species. The whole research was done on self-funding.

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