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Analysis of the spatial and temporal patterns in land use land cover in Belize city from 1991 to 2021

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ABSTRACT

Urban theorists and planning researchers ignore small cities with ports. Rectifying this neglect, we focus on Belize City. We assess the spatial and temporal patterns of land use and cover changes, utilizing remote sensing analysis and multiyear Landsat satellite images. Focusing on the contemporary period (1991-present), we analyze the impacts of the rapid development of the Port of Belize and its consequent effect on the expansion of the urban built environment of Belize City. In addition to analyzing land use land cover changes, we calculated key indices such as NDVI, NDBI, and LST in Belize City. Importantly, local-level clustering of differences in NDBI and NDVI values is analyzed using LISA analysis. Our results show that the urbanized area has increased in the past 30 years, with corresponding reductions in the area under forest and water. Our analyses reveal three distinctive periods of urban changes: 1991–2001, 2001–2011, and 2011–2021. From 1991 to 2001 most of the urban expansion occurred along the Belize River. Significant urban expansion from 2001 to 2011 is related to a private company managing and developing the port, accelerating construction around the port. Finally, from 2011 to 2021, the process of urban sprawl slowed, with only sporadic new construction in the suburbs, due to the master planning at the port. Nevertheless, masterplan implementation delays, numerous appeals, and weak enforcement of regulations have not curbed unplanned urbanization.

1. Introduction

Fifty-five percent of the world's population reside in urban areas, which is projected to increase to two-thirds by 2050 (Baeumler et al., 2021). Accordingly, urbanization is recognized as one of the four demographic mega-trends on account of population growth, aging, and international migration (UNDESA, 2019). Importantly, urbanization patterns are different across the different regions of the world, with some regions in the western hemisphere experiencing a decrease in urban population and, in some cases, shrinking cities are observed (Zhai et al., 2022). For instance, in the Caribbean region, cities are highly differentiated but generally exhibit socio-spatial fragmentation and decline tendencies, with shifts toward growing population concentrations in urban peripheries and age-dependent residents (Jaffe et al., 2008). Urban population dynamics are linked to local economic development and specializations (e.g., ports serving cruise and/or cargo traffic) and social and political trends, which affect urban areas' path dependence, lock-ins, and future trajectories.

Small cities, in general, and those of the Caribbean region have often been neglected by urban researchers and planning scholars (Bell and Jayne, 2009; Potter, 2017) and remain an "underexposed" phenomenon (Jaffe et al., 2008, page 1). The overconcentration

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of global and large cities may be obscuring as much as it illuminates generalizable urban models and patterns that can be employed to understand urban development in small cities. General regional city models, such as “the Caribbean City” (Dehoorne et al., 2018), are unhelpful given the great diversity of urban experiences (with regards to historical experience, size, location, ethnic composition, and countryside-urban and informal-formal relations (Jaffe et al., 2008), vulnerabilities to climate change (Robinson and Wren, 2020) and human agency. Urban scholars call for more focus on “the world of ordinary cities” and “cities off the intellectual map” (Robinson, 2002; Potter, 2017; Kanai et al., 2018) to understand more fully how small cities attempt to develop competitive advantage in the global urban hierarchy; how small cities link with other cities (and non-urban places); what forms they take so that their spatial manifestations can be accessed. Addressing this empirical gap in urban research allows for a much fuller picture of cities to be developed, no matter their size or location (Bell and Jayne, 2009). Focusing on Belize City, a city with a population of 66,083 in 2023 (Belize City Council, 2023, page 1), we acknowledge from the outset that there is not a good critical mass of urban research (Everitt 1986). Too often, urban planning studies in the Caribbean region are combined with planning in Middle America (Clouser et al., 2020) and/or Latin America via a hemispheric lens (e.g., González-Pérez et al., 2022). Moreover, remote sensing studies of urban land use change worldwide focus on sample cities that do not include Belize City (Angel et al., 2011; Shi et al., 2023). To fill this gap, we undertake a pilot study that is data-informed on urban land use changes. Although Belize city's smallness has not precluded it from tourism and global network flows (Seidl et al., 2014; Potter, 2017), the literature on urban planning and land use change is sparse.

Belize City achieved full independence in 1981. Like many post-colonies, it struggled to transition from colonial planning into national planning, experimenting with privatizing land and ports and releasing many government lots quickly to spur local economic development, undermining urban management (Brown and Wolf, 1997). Like many post-colonies, Belize's transition disrupted urban land use planning and management (Brown and Wolf, 1997). Making matters worse, major international mass outmigration from 1981–84 occurred until Belize developed a coherent tourism development plan that boosted the tourism economy. After 1980 foreign direct investment became attracted to the city to enhance its gateway function (Brown and Wolf, 1997). The opening of Port Belize to the cruise industry in 1991 proved pivotal in triggering massive changes in the spatial patterns of land use land cover (LULC) in Belize City. This development stimulated a steady growth in the urban population, including a new foreign resident population whom desired properties in the city's outskirts and demanded imported goods and improved transportation infrastructure. The resulting land speculation and property development produced significant changes in LULC. These trends were exacerbated by the total absence of restrictions on converting rural to urban land uses on the city's fringes (Betancourth, 2011). No planning, poor land management, and rapid and spontaneous urban sprawl posed an increasing threat to the unique biodiversity and ecosystems (Young, 2008). For instance, it is estimated that Belize loses more than 300 acres of mangroves each year, increasing the threat of rising sea levels and carbon dioxide emissions (Cherrington et al., 2020).

The port-urban nexus has been mainly studied in the historical development of ports and cases of contemporary urban regeneration of port waterfronts. While the main thrust of recent research on ports examines international networks and onshore inland port and transportation networks, port scholars underscore that small ports still matter today to small cities (Mortensen et al., 2020); and perhaps even more so (Karimah and Yudhistira, 2022) in terms of their relative impacts on land use. This is especially the case for smaller ports with dual concentrations in container and cruise passengers, primarily where the latter has grown disproportionally in recent years.

Belize City is a water-based delta city at the mouth of Haulover Creek, an essential branch of the Belize River (See Fig. 1). It is the largest city in Belize, with the Port of Belize functioning as the country's leading financial and industrial center. Most of the city is at or below sea level and thus prone to frequent flooding due to heavy rainfall and coastal storm surges related to tropical storms (Betancourth, 2011). In assessing the interrelationships port and Belize city, the popularity of cruising in the Caribbean and Central America and homeporting in Belize city has been affected by the same kinds of over tourism, and “tourism bubbles” that are common to cruise destinations in smaller countries of the region (Munt and Higinio, 1993). Tourism scholars (Renaud, 2020) contend that cruise tourism and the influx of expats drive land speculation and displacement in Belize. However, there is a shortage of studies on Belize city concerning the urban impacts of the ports, such as increasing cruise visitors, containerization, and the ports' externalities on the urban land environment. Therefore, a key question is whether Belize city and the interrelationships with Belize ports are moving on a sustainable pathway.

Belize has experienced a loss of forests from 96.9% (1991) to 85.72% (2014) of total land area (Chicas et al., 2016a,b), with significant deforestation concentrated in the most populous Mayan regions (Emch et al., 2005; Moore, 2007). One of the main drivers of deforestation in Belize is the transition to industrial agriculture, which is revealed in 43.6% of agricultural land expansion, 7.5% of forest loss, and 28.2% of wetland loss (Doyle et al., 2021). These changes in LULC are particularly critical because the natural environment undergirds the basis of Belize's culture and economy, with a large portion of the population dependent on natural resources for their livelihoods and tourism. Natural resources are the country's largest source of income, and related primary activities such as agriculture, fishing, and forestry also depend on the state of the natural environment. Unfortunately, nature is under threat as land degradation and fragmentation caused by human activities worsen and harm biodiversity, further exacerbating climate change's impacts (Shahfahad et al., 2022). Few would disagree that the ecological environment and natural resources must remain critical to Belize's development pathway and its long-term sustainable development.

Belize's tourism industry, closely tied to Port Belize, accounts for about 45% of the country's gross domestic product (GDP) (World Travel & Tourism Council, 2018). Port Belize's main imports include construction materials, food, machinery, and petroleum products, while major exports include bananas, citrus fruits, clothing, fishery products, and sugar (World Integrated Trade Solution, 2023). International trade generates foreign exchange, stimulates employment and tourism, and supports the city's growth. With cruise ship services transferred to Port Coral in 2022, Port Belize and its associated urban development are in a new development stage. The expansion of Port Belize and its impact on the surrounding environment have been questioned for some time (Stevenson,

Fig. 1. General layout of Belize City.

2004). Still, research has been heavily concentrated on rural settings and rural biodiversity change (Penn et al., 2004; Wyman and Stein, 2010; Blentlinger and Herrero, 2020). Assessments of urban land-use change patterns in Belize City remain neglected. Therefore, this study aims to analyze the spatial and temporal patterns of land use and land cover changes and their associated effects on Belize City from 1991 to 2021.

2. Data

Remotely sensed images are highly effective for monitoring urban built-up areas' spatial distribution and growth and provide timely and synoptic views of land cover at fine spatial resolutions (Xu, 2008; Bhatta, 2009; Griffiths et al., 2010; Sen Roy et al., 2022). Our study utilized Landsat satellite data from NASA (https://earthexplorer.usgs.gov/) at two-year intervals between 1991 and 2021. A two-year interval was considered adequate to capture both rapid and slow-occurring changes within the city during the 30-year study period. The images were limited to the relatively cloud-free period of the year, from March to May, consisting of images with less than 20% cloud cover. These images were for Landsat 5–8 Collection 2 Level-2, with a spatial resolution of 30 m, path 019, row 048, and projected coordinate system of WGS_1984_UTM_Zone_16N. Table 1 provides a list of satellite images used in the present study is listed. Level 2 images were utilized for this analysis because these products are atmospherically corrected for surface reflectance and surface temperature images.

3. Methods

3.1. Land use land cover classification change (LULCC)

There are various techniques to classify satellite images. In this research, we explored several techniques to classify the satellite images for Belize City in ArcGIS Pro software. The best results were generated by an unsupervised classification ISODATA technique, which does not apply prior knowledge to the classification process. This technique operates on natural clustering based on the distribution of spectral features of remotely sensed image features without determining the specific LULC type (Keranen and Kolvoord, 2014). The method is based on unsupervised machine learning algorithms exploring no labeled training samples (Olaode et al., 2014). It is useful for improving visualization and retrieval efficiency in image processing (Datta et al., 2008). It is also helpful for matching low-level features to high-level semantics, particularly in learning-based applications (Huang et al., 2011). By detecting the remote sensing confusion matrix, the overall classification accuracy obtained by the unsupervised classification method in 2021 was 84%. Kappa (K) statistics were used to evaluate the classification accuracy, which was 0.81 representing significant accuracy and reli-

Table 1
List of satellite images and the bands used in this study.

Date of image acquisition	Landsat Sensor	R band	NIR band	SWIR band	Thermal band
May 21, 1991	Landsat 5 TM	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (120 m)
May 5, 1993	Landsat 5 TM	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (120 m)
March 16, 1995	Landsat 5 TM	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (120 m)
May 9, 1997	Landsat 5 TM	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (120 m)
April 29, 1999	Landsat 5 TM	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (120 m)
May 3, 2001	Landsat 5 TM	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (120 m)
April 19, 2003	Landsat 7 ETM+	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (60 m)
March 22, 2005	Landsat 7 ETM+	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (60 m)
March 11, 2007	Landsat 7 ETM+	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (60 m)
April 6, 2009	Landsat 7 ETM+	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (60 m)
May 7, 2011	Landsat 7 ETM+	Band 3 (30 m)	Band 4 (30 m)	Band 5 (30 m)	Band 6 (60 m)
May 5, 2013	Landsat 8 OLI/TIR	Band 4 (30 m)	Band 5 (30 m)	Band 6 (30 m)	Band 10 (30 m)
May 17, 2015	Landsat 8 OLI/TIR	Band 4 (30 m)	Band 5 (30 m)	Band 6 (30 m)	Band 10 (30 m)
March 24, 2017	Landsat 8 OLI/TIR	Band 4 (30 m)	Band 5 (30 m)	Band 6 (30 m)	Band 10 (30 m)
April 27, 2019	Landsat 8 OLI/TIR	Band 4 (30 m)	Band 5 (30 m)	Band 6 (30 m)	Band 10 (30 m)
May 18, 2021	Landsat 8 OLI/TIR	Band 4 (30 m)	Band 5 (30 m)	Band 6 (30 m)	Band 10 (30 m)

able results. The main LULC categories revealed by unsupervised classification consisted of developed, forest, herbaceous, and barren land use categories (Fig. 2). Table 2 includes the results of the accuracy matrix for 2021 unsupervised classification of LULC categories.

3.2. Land surface temperature (LST)

LST has been widely used to analyze the spatial patterns of the urban heat island (UHI) effect across large urban areas (Voogt and Oke, 2003). It is a valuable tool for studying the urban thermal environment by analyzing the energy balance at the surface level (James and Mundia, 2014) that can be closely related to the varying land uses and land cover (Falahatkar et al., 2011; Roy et al., 2020). It results from the conversion of natural surfaces to artificial surfaces, which leads to changes in evapotranspiration, and surface radiative properties. It ultimately alters the thermal environment, including changes in temperature, cloudiness, and precipitation (Streutker, 2002; Kaufmann et al., 2007). Biennial local LST levels were calculated from the thermal bands listed in Table 1 using the scaling factor formula below (USGS, 2023):

$$LST = Thermal\ Bands \times 0.00341802 + 149.0 - 273.0 \tag{1}$$

3.3. Normalized difference building index (NDBI)

The NDBI index automatically maps urban built-up areas by considering the unique spectral responses of built-up areas and other land covers (Zha et al., 2003), taking advantage of the unique spectral responses of built-up areas and other land covers (Guha et al., 2019). The method is derived by using the near-infrared (NIR) and shortwave infrared (SWIR) bands to emphasize human-made building areas. Built-up areas and bare soil reflect more SWIR than NIR. Therefore, the formula used to calculate NDBI is given below:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \tag{2}$$

NDBI values range from −1 to 1. Values closer to 1 represent less green vegetation and dominant anthropogenic activities, while values less than 0 indicate water and vegetation. The results of NDBI are shown in Fig. 4.

3.4. Normalized difference vegetation index (NDVI)

The normalized difference vegetation index (NDVI) is one of the critical parameters reflecting vegetation growth and vegetation coverage. It is a standardized index that estimates the photosynthetic activity by a combination of Red and Near Infrared bands that are generally conditioned by the presence of chlorophyll. This index can be utilized to generate an image displaying vegetation or greenness (Rouse et al., 1974; Wright and Sen Roy, 2022). The formula used to calculate NDVI is given below:

$$NDVI = \frac{NIR - R}{NIR + R} \tag{3}$$

where NIR is the reflection value in the near-infrared band, and R is the reflection value in the red band (Blentlinger and Herrero, 2020). NDVI values range between −1 and 1, with values closer to 1 representing higher vegetation coverage and better greening, indicating rich biodiversity. In this case, values between 0 and -1 represent water, barren areas, and clouds (Sen Roy and Fei, 2007). The results of NDVI analyses are shown in Fig. 5.

3.5. Local indicator of spatial autocorrelation (LISA)

To detect the areas of significant change in NDBI and NDVI values over the study period, we conducted a cluster and outlier analysis with a local Moran's I function in the form of local indicators of spatial autocorrelation (LISA) to identify local level clustering

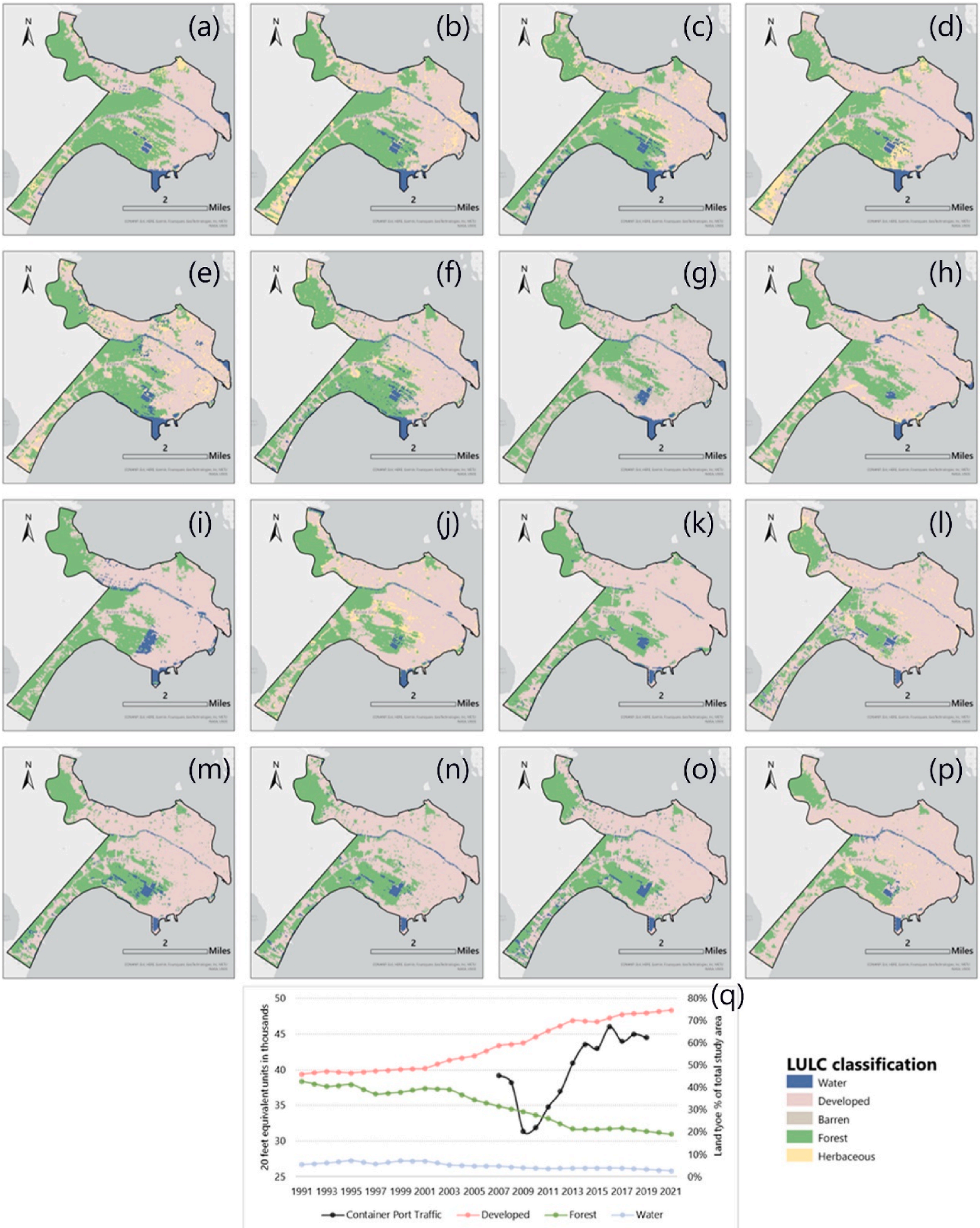

Fig. 2. Land use and land cover changes in Belize City from 1991 to 2021 (a) to (p); (q) total area under different categories from 1991 to 2021.

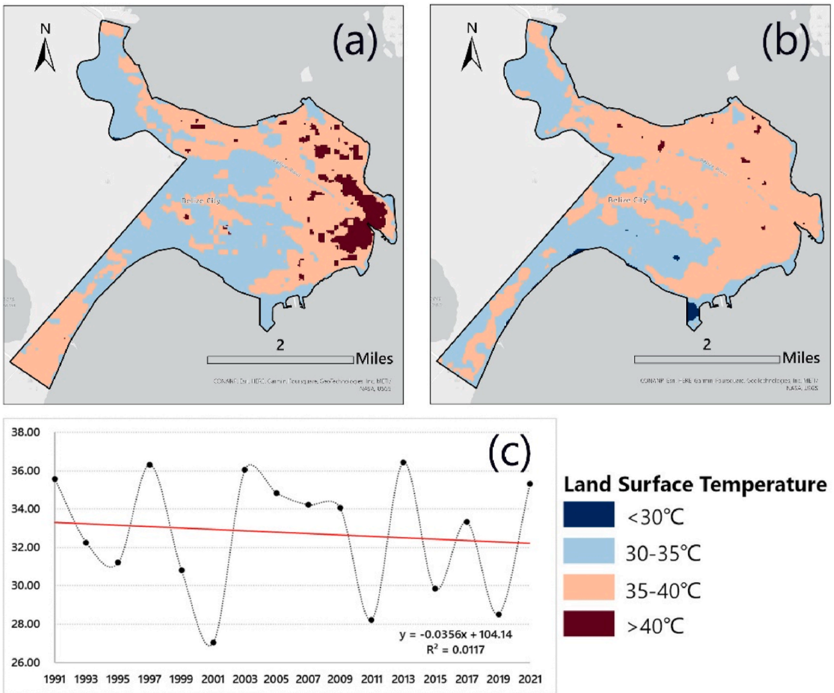

Fig. 3. Spatial patterns of LST (°C) in (a) 1991; (b) 2021; (c) Average values for Belize City from 1991 to 2021.

Table 2
Unsupervised classification accuracy matrix for 2021.

Categories	Water	**Developed (Urban)**	Barren	Forest	Herbaceous	Total	U_Accuracy	Kappa
Water	7.00	0.00	0.00	2.00	0.00	9.00	0.78	0.00
Developed (Urban)	1.00	21.00	3.00	1.00	0.00	26.00	0.81	0.00
Barren	0.00	0.00	7.00	0.00	0.00	7.00	1.00	0.00
Forest	0.00	0.00	0.00	9.00	1.00	10.00	0.90	0.00
Herbaceous	0.00	0.00	1.00	0.00	4.00	5.00	0.80	0.00
Total	8.00	21.00	11.00	12.00	5.00	57.00	0.00	0.00
P_Accuracy	0.88	1.00	0.64	0.75	0.80	0.00	0.84	0.00
Kappa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.81

(Anselin, 1995). This method utilizes the squared differences and/or dissimilarity, with smaller statistics representing positive spatial autocorrelation and large values representing negative spatial autocorrelation. The spatial weighting used in this analysis was inverse distance weighting. The output of this analysis reveals the presence or lack of clusters of high or low differences in the phenomena being studied (Perlman and Sen Roy, 2021). Specifically, the outputs are categorized into four statistically significant categories (i.e., 0.05 level or higher), which include clusters of high differences (High-High), a low difference (Low-Low), and outliers consisting of higher differences surrounded by low differences (High-Low) and lower differences surrounded by higher differences (Low-High). Thus, the cluster and outlier analysis indicate the extent of significant spatial clustering of levels of differences.

4. Results and discussions

4.1. Land use land cover changes (LULCC)

The establishment of the Port of Belize on the southern coast of Belize City as an entry point for cargo led to the rapid inland expansion of the city. The settlement and expansion patterns of Belize City occurred along two main highways, Northern and Western (also known as Coney Drive), that connect the city to the rest of the country. Historically, the main urban functions were concentrated downtown, with residential and commuter towns expanding along the two main highways, creating severe traffic bottlenecks. Fig. 2 shows the changes in the proportion of various types of LULC from 1991 to 2021, spatially and overall. It is evident from the analysis that the urban areas expanded westward from the coast to the interiors along the two highways in the north and west over time. This expansion of Belize City outward from the center to the outskirts, in some cases, depopulation of the city center has been termed the "doughnut" effect (Betancourth, 2011). Over time, the analysis of the total area under various LULC categories revealed that the area under urban areas grew over the past 30 years, gradually encroaching on forests and almost all other land use categories. The total area under urban land use shows a sustained increase over the years, with a steeper increase since 2003, while the reverse trend is ob-

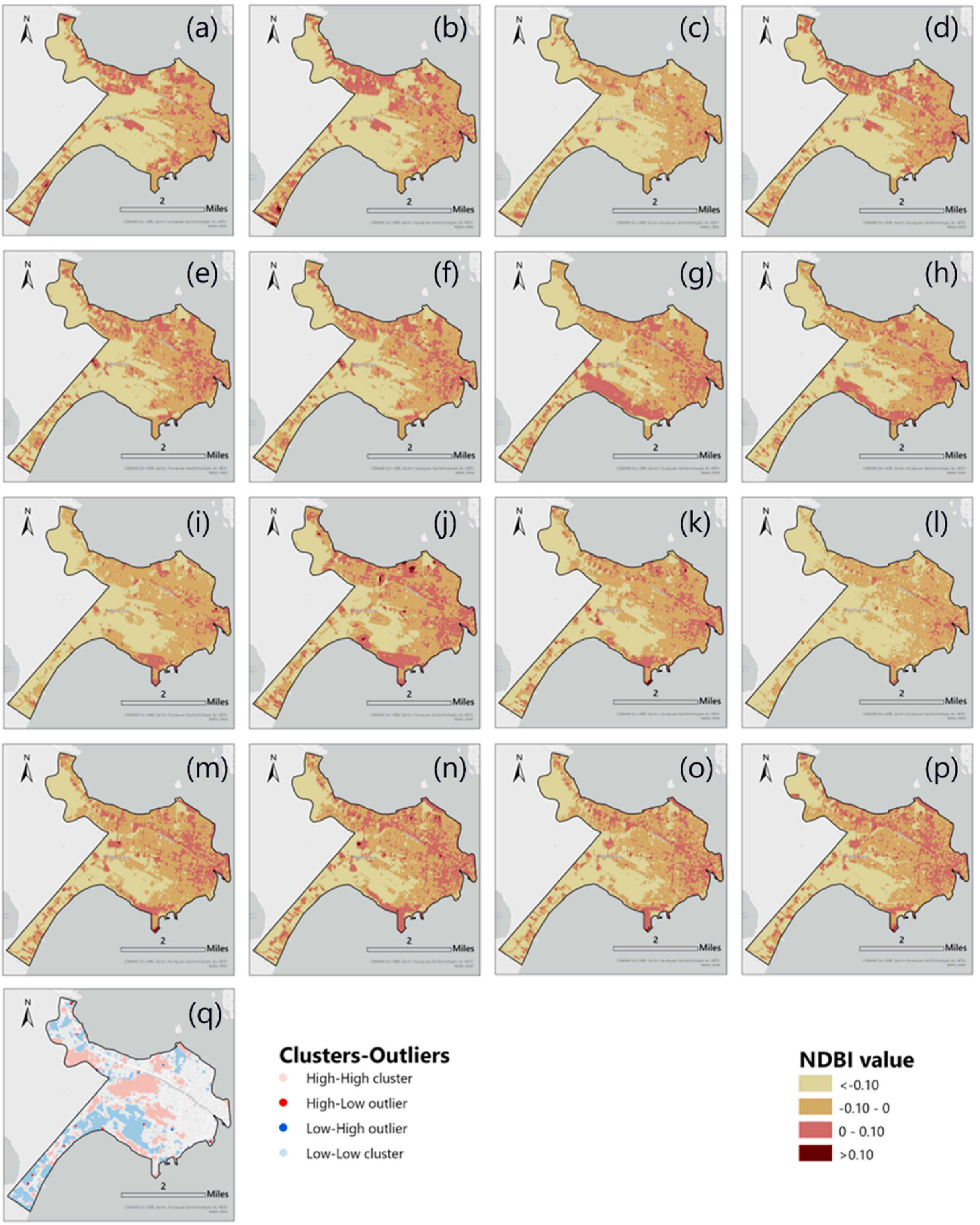

Fig. 4. Spatial patterns of local level differences in NDBI values from 1991 to 2021 (a) to (p); (q) Results of cluster and outlier analysis for the absolute difference in NDBI values between 1991 and 2021.

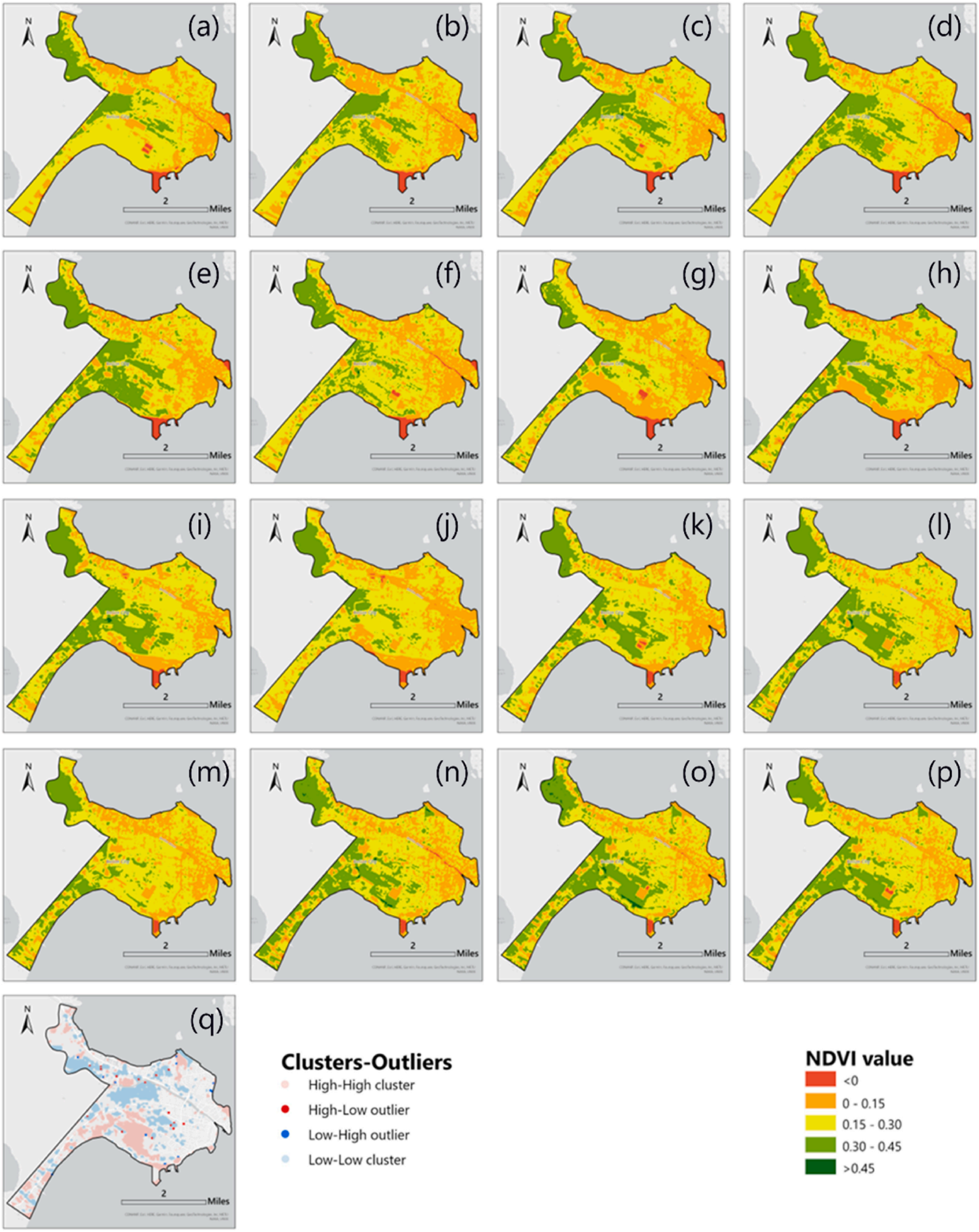

Fig. 5. Spatial patterns of local level differences in NDVI values from 1991 to 2021 (a) to (p); (q) Results of cluster and outlier analysis for the absolute difference in NDVI values between 1991 and 2021.

served for forests (Fig. 2q). The gap between the areas under forest, water, grasslands, and the developed areas increased, leading to more imbalance. These trends can be attributed to opening a channel and turning basin, which allowed larger vessels to be docked with larger payloads, saving time, and reducing transportation costs, thus giving the port a competitive advantage in the region. Over the years, the port has undergone substantial changes in investment and ownership to handle higher throughput and improve customer service levels. Changes included digitalization and new operations in a new terminal operating system in 2020. As a result, by 2021, about three-quarters of the land area in the city were developed urban areas, with less than 20% being vegetation, and the proportion of water area remaining the same. In the past three decades, the transformation of land use types was mainly the conversion of other types of land into urban development land. From 1991 to 2001, 1.08 square miles of additional land types were converted to urban land, mainly in the Belize riverfront area. From 2001 to 2011, 0.97 square miles of other types of land were converted to urban land, mainly in the southern port area of the city. Since 2002, the privatization of the Port of Belize (Port of Belize, 2022) has accelerated the upgrading of port infrastructure and new building construction that has enlarged the port's footprint. From 2011 to 2021, 0.71 square miles of other land types were converted to urban land, mainly in the western and southwestern suburbs of the city. Due to the expansion of urban development and agriculture, deforestation has accelerated since 2000, resulting in water pollution, considerably impacting local fisheries' development (Port of Belize, 2022). Beginning in 2012, Port Coral construction commenced to manage urban development better.

4.2. Changes in LST

The spatial patterns of LST across Belize City did not significantly change during the study period. The overall values ranged from 29 to 43 °C in 1991 to 28–41 °C in 2021, a slight decrease, which is indicative of the “doughnut” effect mentioned above and indicative of the movement of the population toward the outskirts (Fig. 3a and b). The main areas of decrease in LST were concentrated in the old part of the city that has undergone substantial decay and depopulation over the years, with more remarkable development near Port Belize in the southern part of the city. Despite the overall decline in the range of LST over the years, the spatial extent of higher LST values expanded west and north from the city center to the mouth of the Belize River in the east (Fig. 3). This is further validated by the weak negative trend in annual average temperatures for Belize City for the entire study period (Fig. 3c). Similar spatial patterns of impacts of ports on urban land use patterns have been observed in other cities. For instance, in Qingdao, China, over time, areas with intensive land development have gradually shifted from coastal to inland areas, and industrial transfer has driven the development of surrounding towns (Yan et al., 2021). In Ajmer Port in Davao City, Philippines, the port area has increased by 21.68 ha in nine years, while the area of water and green space has decreased significantly. This indicates the impact of port construction on the land use land cover of the district (Li et al., 2019).

4.3. Changes in NDBI and NDVI

The spatial patterns of NDBI match the changes in the expansion of developed urban LULC from the mouth of the Belize River to the west and north along the two main highways (Fig. 4). Furthermore, it is noteworthy that there is a substantial increase in NDBI values near Port Belize, located on the south-central coast. The expansion of Belize City has occurred through land reclamation, deforestation of adjacent mangrove forests, and the reclamation of the wetland and its habitats for residential housing, industrial and commercial subdivisions, tourism use, and related infrastructures (Betancourth, 2011). The downtown of the city, located in the east close to the mouth of the Belize River, has become overcrowded with no space for expansion with its location on the coast, making it highly vulnerable to the effects of sea level rise and flooding. Active efforts are thus made to pump out the rainwater to avoid flooding resulting from limited infiltration because of high proportions of impervious surfaces. This has resulted in land subsidence because of the lowering of the water table, which becomes evident in buckling and potholing of city streets, cracking of building foundations, and threats to city infrastructure, including sewer, water lines, bridges (Betancourth, 2011). Furthermore, the privatization of Port Belize in 2002 accelerated the construction of its cargo-handling equipment and river yards. This led to a steep increase in the handling of containers, from 30,000 TEUs to 45,000 TEUs in 2019 (World Bank, 2022). This is evident in the clustering of higher NDBI values near the port.

The spatial patterns of NDVI were almost opposite to that observed for NDBI. The lowest values were in the city's core in the east near the coast (Fig. 5). Over the years, the city's expansion associated with deforestation and reclamation of wetlands in the north and west resulted in the spread of low NDVI values across the city in both directions. Specifically, at the decadal level from 1991 to 2001, the areas where NDVI decreased significantly were distributed on both sides of the Belize River, which overlapped with increased NDBI values. It followed from 2001 to 2011 when the areas where NDVI decreased significantly were mainly concentrated near the Port of Belize, which also overlapped with increased values of NDBI. Finally, from 2011 to 2021, the areas where NDVI increased were in the north and western parts of the city. Most of the changes in NDVI were generally clustered in the northern and western parts of the city, where most of the city's expansion is concentrated. However, it is noteworthy that the trends in overall average NDVI values across the city showed an increasing trend that can be attributed to the creation of public green spaces in the city and retention of green spaces in the old urban residential areas, part of the increasing efforts toward a more sustainable planned city development.

Finally, the results of local cluster analysis of the absolute difference in NDVI and NDBI values between 1991 and 2021 (Figs. 4q and 5q) reveal distinct clusters of significantly high and low contrasts. The spatial patterns of the clusters for NDVI values are almost a mirror image of the NDBI values. Specifically, the most significant high-high cluster for NDBI difference (low-low clusters for NDVI) was in the relatively newer urbanized part of the city in the west along the Belize River and northern highway. It is also noteworthy that despite the city's expansion along the western highway, the presence of low-low NDBI difference (high-high clusters of NDVI difference) indicates the increase in vegetation and decline in barren (in this case) land.

5. Conclusion

We utilized biennial, Landsat satellite images from 1991 to 2021 to assess the changes in land use and land cover in Belize City. We calculated LST, NDVI, and NDBI values for each two-year period to document the differences in vegetation and urban development over time with the expansion of the Port of Belize for cruise and cargo. Significantly, port development has facilitated trade, population, investment, and economic growth, improving the area's attractiveness for investment and real estate development. Housing has become less affordable, pushing poor urbanities into informal settlements often located within ecologically sensitive areas such as mangroves and wetlands. The IDB (2019, p. 98) notes that informal settlements have expanded the city's footprint, taking up 3.49% of Belize's land area, and housing 3.7% of the urban population. The net effect restored Belize's urban population, which has declined since the last century. Nonetheless, it also accelerated unplanned urban expansion, particularly along the two main highways and the Belize river in the north and west. Our main findings are:

(1) The LULC in Belize City from 1991 to 2021 mainly changed from forests, water bodies, grasslands, and wastelands, to developed urban areas. Large areas of land were deforested or filled in for urban land uses. The proportion of urban area to the total area of the study area increased from 46% in 1991 to 75% in 2021. The urbanized areas are mainly inland toward the west, northwest, and southwest of the study area.
(2) The expansion of Belize City also led to the spread of higher LSTs from the city's core at the coast to inland areas. However, a decline in LSTs in the city's old core indicated the depopulation and decay of the downtown area, referred to as the “doughnut” effect.
(3) The spatial patterns of the NDBI and NDVI values were expectedly to mirror patterns. As a result of the city's expansion inland from the coast, increased NDBI values overlapped with decreased NDVI values.
(4) The expansion of Port Belize is clear from the steep increase in NDBI values and decrease in NDVI values.
(5) The local level cluster analysis of the absolute differences for NDVI and NDBI values between 1991 and 2021 revealed significant clusters in the newly urbanized inland areas of Belize City.

These results clearly indicate that Belize City needs to move along a more sustainable pathway with planning becoming a priority.

Sustainable planning in Belize City will be a considerable challenge as the urban fabric is a mix of historical and new patterns blended with little regard for integration and proper functioning. Outside of port enclaves, urban planning, and implementation needs prioritization. Despite various efforts (e.g., Development Plan (1997), Master Plan for Belize City (2011), Comprehensive National Transportation Master Plan for Belize (2018], National Sustainable Tourism Master Plan for Belize 2030 (2011) and Downtown Rejuvenation Project (2013), planning has neither incorporated land management of new areas of the city nor zoning that would enable various plans to be implemented and ensure that any building in a hazard or flood-prone area should be held to high construction standards (IDB, 2019). Unsuccessful master plans, approval delays, numerous appeals, and weak enforcement of regulations indicate tensions among planning, land use, and economic development (Mycoo, 2017). In 2016, the Belize Association of Planners (Belize Association of Planners, 2023) and planners were established to create working partnerships among the state, port, private sector, and civil society so that Belize City can transition toward a resilient coastal city. Current and future generations of Belize citizens deserve sustainable urban land use planning and more attention from the urban planning and research communities.

Land-use and land cover changes assessment are important for urban managers, local stakeholders, and researchers. Land-use land cover changes affect urban heat islands and urban thermal comfort in cities and ports (Karimi et al., 2021, Shahfahad et al., 2022). We hope our research will stimulate more research on ‘ordinary cities’ and places and small cities hitherto off the intellectual map, like Belize City, encourage a refocus on green spaces (Mosisa et al., 2022) and the rural areas in the surrounding metropolitan areas (Santhosh and Shilpa, 2023).

Ethical statement

We admit that to the best of the authors’ knowledge this submission has no potential ethical issues.

Author contributions statement

CL and SSR: Conceptualization, data curation and analysis, writing-original draft preparation, formal analysis, visualization.

SSR: supervision, methodology, writing-review and editing, visualization, validation.

RG and LRB: Writing-review and editing, validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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