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Modeling and Monitoring Urban Expansion and Service Inequality Using GIS-Based Spatial Analysis and Urban Morphology Indicators: A Case Study of Tripoli, Libya

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نمذجة ورصد التوسع الحضري وعدم المساواة في الخدمات باستخدام التحليل المكاني القائم على نظم المعلومات الجغرافية (GIS) ومؤشرات المورفولوجيا الحضرية: دراسة حالة لمدينة طرابلس، ليبيا

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Abstract
Libyan cities have changed fast because of quick growth. This growth often happened without strong planning. It created worries about urban sprawl and unfair service access. This study builds a GIS method to track these changes in Tripoli, Libya. We use open data on city form, land cover, and settlement patterns. We also use locations of public services. We measure how Tripoli grew and where services are missing. Satellite images and spatial measures show strong built-up growth in four decades. Sprawl became stronger in the 2000s. Shannon entropy rose from 0.74 in 1984 to 0.90 in 2010. This rise shows growth became more spread out. At the same time, new edge areas gained people but not enough services. Many residents travel longer for health care and schools. We combine OpenStreetMap service points with population grids. Then we map service gaps and find areas with weak coverage. Results show a clear pattern of service inequality. Unplanned growth zones have fewer hospitals, schools, and utilities per person. Central planned districts have better service levels. This GIS method helps planners see growth shape and service gaps. It also supports better planning decisions. We end with policy steps for better growth control. We suggest guided expansion and focused service investment. These steps can support fair and stable growth in Tripoli and similar cities.

Keywords: Urban Expansion; GIS; Spatial Inequality; Urban Morphology; Tripoli; Service Accessibility.

الملخص
شهدت المدن الليبية تحولات متسارعة نتيجة للنمو السريع، والذي غالباً ما حدث في غياب تخطيط عمراني محكم. أدى هذا الوضع إلى مخاوف بشأن الزحف العمراني وعدم المساواة في الوصول إلى الخدمات. تقدم هذه الدراسة منهجية تعتمد على نظم المعلومات الجغرافية (GIS) لتتبع هذه التغيرات في مدينة طرابلس، ليبيا. نستخدم بيانات مفتوحة المصدر حول الشكل الحضري، والغطاء الأرضي، وأنماط الاستيطان، بالإضافة إلى مواقع الخدمات العامة. قمت بقياس كيفية نمو طرابلس وتحديد المناطق التي تفتقر إلى الخدمات.
تُظهر صور الأقمار الصناعية والمقاييس المكانية نمواً قوياً في المناطق المبنية على مدى أربعة عقود، حيث ازداد الزحف العمراني حدةً في العقد الأول من القرن الحادي والعشرين. ارتفع مؤشر "شانون إنتروبي" (Shannon entropy) "من 0.74 في عام 1984 إلى 0.90 في عام 2010، مما يشير إلى أن النمو أصبح أكثر تشتتاً. وفي الوقت نفسه، شهدت المناطق الطرفية الجديدة زيادة سكانية دون توفر خدمات كافية، مما يضطر الكثير من السكان لقطع مسافات أطول للوصول إلى الرعاية الصحية والمدارس.
قمت بدمج نقاط الخدمات من خرائط الشوارع المفتوحة (OpenStreetMap) مع الشبكات السكانية، ومن ثم رسمت خرائط لفجوات الخدمة لتحديد المناطق ذات التغطية الضعيفة. تُظهر النتائج نمطاً واضحاً لعدم المساواة الخدمية؛ حيث

تحتوي مناطق النمو غير المخطط لها على عدد أقل من المستشفيات والمدارس والمرافق لكل فرد، بينما تتمتع الأحياء المركزية المخططة بمستويات خدمة أفضل. تساعد هذه المنهجية المعتمدة على نظم المعلومات الجغرافية المخططين في رؤية شكل النمو وفجوات الخدمة، كما تدعم اتخاذ قرارات تخطيطية أفضل. نختتم الدراسة بخطوات للتحكم في النمو بشكل أفضل، وأقترح التوسع الموجه والاستثمار الخدمي المركّز، وهي خطوات يمكن أن تدعم نمواً عادلاً ومستداماً في طرابلس والمدن المماثلة.

الكلمات المفتاحية :التوسع الحضري؛ نظم المعلومات الجغرافية(GIS) ؛ عدم المساواة المكانية؛ المورفولوجيا الحضرية؛ طرابلس؛ إمكانية الوصول للخدمات.

Introduction

Unplanned city growth is a major issue in Libya after conflict. City growth has moved faster than infrastructure growth. Libya's urban share rose from 49% in 1970 to near 80% by 2016. Many people moved toward coastal cities like Tripoli and Benghazi. Today, about 77–85% of Libyans live in urban areas. Most live along the fertile coast. Large inland areas remain lightly settled. This fast growth often lacked order and control. The problem became worse during unstable periods. Benghazi is one clear example. Conflict years helped push outward growth. Its built-up land doubled from 32,000 to 64,000 hectares since 2009. Much of this growth was informal. Many homes were built without permits. Some were built on land meant for farming. Officials warn that these areas lack key services. Roads are often weak or missing. Green areas are limited. Schools are not enough. Water and sewage networks are also limited. These gaps create long-term pressure on living conditions. Tripoli faces similar pressure. Displacement also shaped Tripoli's growth. The 2019–2020 fighting near Tripoli moved many families. New districts expanded with little formal control. Service supply did not match this growth.

Fast growth and weak control changed Tripoli's urban pattern. The city shows urban sprawl and uneven service spread. Urban sprawl means cities spread into new land. The spread is often low-density and scattered. Sprawl can be measured using city form indicators. These include built-up change, density shifts, and Shannon entropy. Shannon entropy measures how spread-out urban land is. In Tripoli, sprawl shaped a broken city form. The core stayed dense. The outer belt grew in a loose pattern. This form harms service delivery. Fringe areas often lack schools and clinics. Public transport is also weak. Other services are limited too. This creates service inequality across the city. Central neighborhoods are better served. Outer districts depend on longer trips for daily needs. This adds stress and deepens social gaps.

Libya's institutional context further complicates these issues. Decades of centralized planning during the late 20th century were followed by governance breakdown after 2011, weakening urban management. *"Libya faces inadequate urban planning and management; weak governance and institutional capacity; lack of essential services and infrastructure; and social exclusion and inequality,"* according to a recent housing sector assessment. Public investments have historically been concentrated in primate cities (Tripoli and Benghazi), attracting migrants from neglected towns and villages. The result is intense pressure on Tripoli's urban fabric – booming population, housing shortages, and informal expansion into peri-urban lands. Tripoli's population is now over 1.1 million within a metropolitan area of ~1,140 km², and the city's growth has increasingly taken the form of outward sprawl into former agricultural zones without accompanying services.

These patterns show why spatial tools are needed. Cities need close tracking of growth and service spread. Geographic Information Systems and remote sensing support this task well. They help measure where cities grow and how fast. They also show whether services follow this growth. Urban form indicators help describe growth shape. These include built-up area size, patch density, and entropy. Service maps can be placed over population data. This helps find missing services and high-need zones. This study uses Tripoli, Libya as a test case. It presents a GIS method to model growth and service inequality. The study uses open spatial datasets only. These include satellite-based urban maps. They also include OpenStreetMap service points and population grids. Together, they help analyze recent growth patterns. They also reveal gaps in service access.

Literature Review

Uncontrolled city growth and service inequality are common in developing cities. Many studies describe this problem. Researchers show that sprawl wastes land and raises infrastructure costs. It also deepens social gaps. Population increase is a main driver. Rural to urban migration adds pressure. Weak planning control worsens the problem. In Libya, strong urban growth began after 2000. Internal migration and housing demand increased sharply. Urban planning systems could not respond fast enough. Cities expanded in an unorganized way. This pattern matches other fast-growing cities without growth control.

Urban morphology indicators help describe sprawl using numbers. Shannon's entropy is one common measure. It shows how urban land spreads across space. Values range from zero to one. Low values show compact growth. High values show spread growth. Yeh and Li used entropy in China's Pearl River Delta. They showed how cities spread outward over time. Their work proved entropy works well for sprawl study. Many later studies followed this method. Tripoli shows the same pattern. Its entropy increased over time. By 2010, values reached about 0.90. This value signals very dispersed growth. Other measures support this result. These include patch number and patch size. Density change is also used. Boundary shape measures add detail. Alsharif and Pradhan used six metrics in Tripoli. Their study showed growing fragmentation in most districts. Only two districts showed controlled growth. Together, these measures explain urban form change. Rising patch counts and complex edges show uncontrolled expansion.

Remote sensing plays a key role in sprawl research. Satellite images from different years show growth clearly. In Tripoli, Landsat and SPOT images were used. These images cover years like 1976, 1984, 1996, 2002, and 2010. Change detection shows how the city expanded. NASA images confirmed strong growth between 1976 and 2002. Later images show wider spread east and west. Urban areas replaced former farm land. Vegetation loss appears clear in false-color images. This change links to the Great Man-Made River project. Water reached Tripoli by the mid-1990s. This allowed housing growth on dry land. Alsharif et al. studied Tripoli from 1984 to 2010. Their work showed faster sprawl after 2000. Entropy values kept rising. They concluded the city grew in a scattered way. They stressed the need for clearer planning rules.

Urban expansion in Libya must also be understood in the context of governance and conflict. *Alshebani (1995)* and *Al-Sanusi (2005)* (as cited by Shura Council studies) pointed out significant spatial disparities between Libya's primate cities and other regions. Past national plans called for promoting equality in public services across regions, but implementation faltered due to centralized decision-making and, later, institutional breakdown. The wars after 2011 exacerbated urban sprawl – *AFP (2021)* reported that in Benghazi, thousands of families displaced by fighting built informal housing on the city outskirts. These informal settlements grew without permits or infrastructure, to the point where half of Benghazi's buildings today are unlicensed constructions outside the official plan. Such scenarios echo experiences in other conflict-affected countries where urban growth becomes a self-help process in absence of effective governance.

Unplanned growth often leads to service inequality. This means people do not share services equally. Health care, schools, water, and sanitation are affected. New edge neighborhoods usually have fewer facilities. People there travel farther to reach services. Many studies use GIS to measure these gaps. GIS tools map service points and nearby populations. Distance or travel time is then measured. This shows how many people are served. Global health studies use travel-time maps. These maps show access within 30, 60, or 120 minutes. The World Health Organization uses this method. In Libya, HeiGIT applied similar analysis. Their results show rural people live far from hospitals. In Tripoli, most residents live closer to services. Yet differences still exist inside the city. Central districts host major hospitals and universities. Outer districts depend on small clinics or none. Health surveys in Libya support this finding. More than 90% of Tripoli patients reach clinics within 30 minutes. In smaller towns, travel can take several hours. Some people avoid local clinics due to low service quality. These trends show strong urban and rural gaps. They also reveal inequality inside the city itself.

Table 1 Key urban morphology and accessibility indicators for analyzing urban expansion and service inequality. Higher patch density and entropy, and lower service accessibility values, are associated with more sprawl and greater service gaps.

Indicator	Definition and Relevance
Built-up Area	Total urbanized land area. Growth in built-up area over time indicates urban expansion.
Urban Patch Density	Number of discrete urban patches per unit area. Higher patch density implies fragmented, sprawling development (many separate settlements).
Largest Patch Index (LPI)	Percentage of total urban area in the single largest cluster. A decreasing LPI over time can indicate sprawl (development spreading out rather than concentrating).
Shannon's Entropy	Measure of urban land dispersion (0 = compact, 1 = dispersed). Rising entropy signifies more dispersed, sprawling urban growth.
Service Accessibility	Proportion of population within a given distance or travel time of key services (e.g., hospitals, schools). Lower accessibility in new outskirts reflects service inequality.

Studies focused on Libya reach similar conclusions. Tripoli grew very fast and without control. Service delivery could not match this speed. UN-Habitat reported limited service improvement in new urban areas. Local governments lack funding and clear roles. A health review in 2009 listed national facilities. Libya had 96 hospitals and 1,355 basic health centers. There were also 37 polyclinics. Most advanced services were in Tripoli and Benghazi. This leaves rural and fringe areas dependent on basic centers. These centers differ in staff and equipment. Political division in Libya adds more difficulty. Municipal bodies struggle to link land planning with service supply.

Methodology

This study uses a GIS-based spatial analysis method. It combines satellite data, open datasets, and spatial measures. The study area is the Tripoli metropolitan region in Libya. It includes the city center and nearby growing districts. These outer areas expanded strongly in recent years.

Data were taken only from open sources. Urban form and services were both studied. To track city growth, satellite images were collected. Land use and land cover maps were used for several years. Data from the Copernicus Climate Change Service were selected. These maps cover years 2000, 2010, and 2020. They classify built-up land and other surface types. The data have fine spatial detail. Older satellite images were also used. Landsat 5 TM and Landsat 7 ETM+ images were selected. These images cover earlier years like 1984 and 1996. This choice follows earlier Tripoli research methods.

Population data came from the Global Human Settlement grid. This dataset was produced by the European Commission. It shows population spread from 2000 to 2020. The data have a 100-meter grid size. These values were grouped to estimate service coverage. Population was used as a proxy for residence locations.

Service location data came from OpenStreetMap. Humanitarian datasets were also used. Health facility data were downloaded from the Humanitarian Data Exchange. These data were mapped by the Humanitarian OpenStreetMap Team. Only facilities inside Tripoli were selected. These included hospitals, clinics, and basic health centers. Each facility had mapped coordinates. Education service data were also collected. School locations were extracted from OpenStreetMap.

As of the end of 2025, OSM data for Tripoli contains hundreds of mapped amenities in these categories – though we acknowledge OSM's data completeness can vary. To complement OSM, we referenced local sources and maps for any major facility missing from OSM (for example, verifying the location of Tripoli's largest hospitals like Tripoli Central Hospital and Abu Salim Hospital). Additionally, administrative boundary data (Tripoli's district boundaries) were obtained from the geoBoundaries database (Admin Level 2 for Tripoli District) to enable aggregating statistics by district.

All spatial data were projected to a common coordinate system (WGS 84 / UTM zone 33N) for analysis. We performed necessary preprocessing such as image classification (for Landsat scenes of 1984 and 1996, we did supervised classification into built-up vs non-built-up to estimate urban extent, using ground truth from historical maps), data cleaning (removing duplicate or incorrectly located OSM points), and ensuring temporal data alignment (e.g., using population estimates corresponding to the imagery year when analyzing a given period).

Urban Expansion Modeling: We applied several urban morphology indicators to quantify Tripoli's spatial growth. Key metrics included:

- **Built-up area**: total built-up land in square kilometers for each year of analysis. From classified LULC maps (2000, 2010, 2020 and earlier analogs), we computed the urban footprint area. The change in built-up area over time gives a basic measure of expansion intensity.
- **Urban Expansion Intensity Index (UEII)**: a metric used to evaluate the speed and extent of urban expansion in a given period. UEII is defined as the ratio of new urban land growth to total land area available, per unit time. We calculated UEII for each intercensal period (e.g., 1984–1996, 1996–2002, 2002–2010, 2010–2020) for Tripoli's metropolitan area. This index reveals which time intervals saw the fastest expansion. Previous studies reported Tripoli had a high UEII, reflecting rapid outward growth, and our calculations provide updated values.
- **Shannon's Entropy (Hn)**: we divided the metropolitan area into concentric zones (buffers at 1 km intervals from the city center) and computed the entropy of the distribution of built-up land among these zones. The formula used (for each year) was: $H_n = -\sum_{i=1}^{n} p_i \log(p_i)/\log(n)$, where $p_i$is the proportion of total urban area in zone i and n is the number of zones. This yields a normalized entropy between 0 and 1. An increasing entropy over years indicates urban land becoming more spread out (sprawl). We also mapped the *change in entropy* per zone between time periods, to see which directions around the city had the most sprawl (following Alsharif et al.'s approach of subtracting older from newer entropy values per zone).
- **Patch and density metrics**: Using a raster-based approach, we identified contiguous clusters of urban cells for each time slice. We measured number of urban patches, mean patch size, and largest patch size. A rise in patch count and drop in mean size can imply fragmentation of the urban landscape (development leapfrogging into new isolated clusters). We also computed urban population density (people per km² of built-up land) as an indicator – a decline in this density might signal sprawl if population growth is not keeping up with area expansion.

- Other morphology descriptors included qualitative observations of urban form (e.g., examining satellite images for the emergence of linear sprawl along highways vs. radial sprawl). We used GIS overlay to identify what land types were converted to urban use (e.g., agricultural land loss).

Service Distribution Modeling: To evaluate service inequality, we implemented an accessibility analysis for health and educational services in Tripoli. The primary measure used was travel distance (Euclidean as a proxy, due to limitations of routing without a detailed network model). We took each mapped facility and generated service catchment zones. For hospitals and large clinics, distance zones were created. Buffers of 1 km, 3 km, 5 km, and 10 km were used. Population data were placed over these zones. People inside each zone were counted. This showed how many residents live near hospitals. The result shows access levels by distance. For example, it shows the share of people within 5 km of a hospital. The same method was used for schools. Smaller distance limits were applied. Buffers of 0.5 km, 1 km, and 2 km were selected. These distances fit local school access needs.
For a more refined approach, we also leveraged the Libya Accessibility Indicators dataset by HeiGIT. This dataset uses travel-time isochrones (by car) computed from OSM road data and overlays them with population data. It provides, for each region, the share of population within given travel times to the nearest service. From this, we extracted Tripoli-specific figures: for example, what percentage of Tripoli's population can reach a hospital within 10 minutes, 30 minutes, etc., by car. At the national level, the dataset indicated a relatively high accessibility in coastal cities versus very low accessibility in interior regions. Within Tripoli, we expected most areas to be within 15–20 minutes of a hospital, except perhaps some peri-urban fringes.
In addition, we calculated service density indicators: number of key facilities per 10,000 people in different parts of the city. Using Tripoli's municipal sub-districts, we compiled counts of health centers and schools in each, divided by the population of that sub-district (from WorldPop or census estimates). This highlighted disparities – e.g., a newer suburban district might have only 1 primary clinic for 20,000 residents, whereas an older central district might have 1 clinic per 5,000 residents. We also qualitatively examined whether the spatial distribution of services aligns with the pattern of urban growth. A well-planned expansion would feature new services introduced as the city grows, whereas in Tripoli's case, we anticipated a lag, with many services still clustered in older areas.

Spatial Analysis and Visualization: All the above computations were performed in QGIS and Python (using libraries such as GeoPandas for spatial data manipulation). We produced maps and figures at each step to support analysis and interpretation. For example, we mapped the built-up area in 2000, 2010, 2020 to visualize expansion corridors. We created a land cover change map showing areas that transitioned to urban use over 20 years. This map was overlaid on a city base map to see which neighborhoods emerged. We also generated a service map plotting all hospitals and clinics against population density, highlighting neighborhoods beyond a 3 km radius from any major facility. Finally, summary charts were prepared, such as a time-series plot of Shannon entropy and a bar chart of population within certain distance bands of services.
All figures are presented with appropriate legends and scales. Whenever using external images or data, we have provided citations and ensured they are from open sources (e.g., NASA, OSM, etc.). Figure 1 below is one of the visualizations from our analysis, illustrating the progression of Tripoli's urban footprint and population distribution over time.

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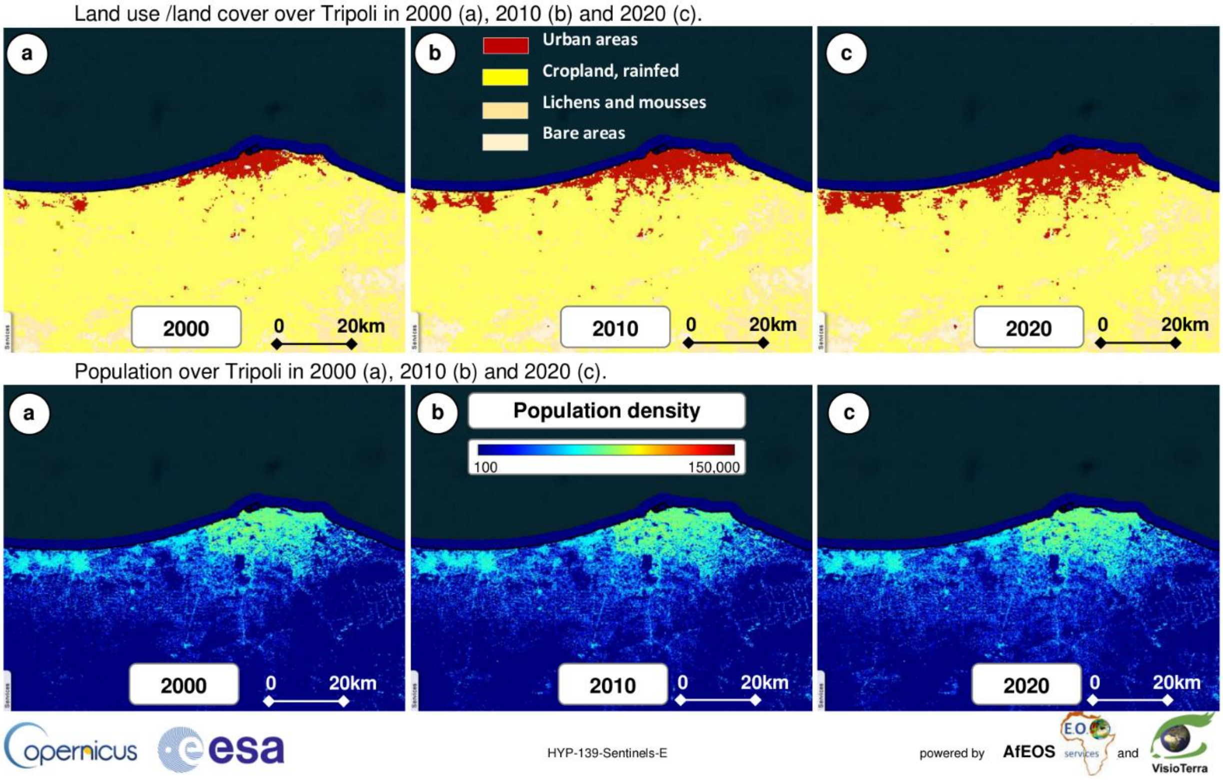

Figure 1 Land use, land cover, and population density changes in Tripoli are shown over time. Panel (a) shows the year 2000. Panel (b) shows 2010. Panel (c) shows 2020. Red areas represent built-up urban land. Blue and green shades show population density levels. Darker shades indicate higher population. The maps are based on Copernicus and JRC data. They show strong urban growth from 2000 to 2020. Expansion is clear toward the west and east along the coast. Population maps below follow the same pattern. By 2020, more people are spread into suburban areas. Sources: C3S land cover and JRC GHS population data (processed by VisioTerra/ESA).

We ensured that each dataset's limitations are considered. OSM data might under-map some facilities (we cross-checked with ancillary sources). The travel time analysis assumes normal traffic and road conditions (in reality, congestion or security checkpoints could affect travel). Despite these caveats, the combination of methods provides a robust picture of where Tripoli has grown and who has access to what.

Experiments and Results

Urban Expansion Analysis

Our analysis confirms that Tripoli has experienced extensive urban sprawl in recent decades. The city's built-up area has expanded dramatically in all directions, resulting in a more dispersed urban pattern. Table 2 summarizes the calculated Shannon entropy values for Tripoli's urban land in four benchmark years (based on concentric zone analysis):

Table 2 Shannon entropy of Tripoli's urban footprint over time. Values closer to 1 indicate a more spread-out (sprawling) urban distribution. Data source: calculated from classified satellite imagery.

Year	Relative Shannon Entropy (H_n)	Interpretation
1984	0.74	Moderate dispersion (some sprawl)
1996	0.79	Increasing dispersion
2002	0.83	High dispersion (sprawling)
2010	0.90	Very high dispersion (strong sprawl)

As shown in Table 2, Tripoli's entropy rose from 0.74 in 1984 to 0.90 in 2010, a substantial increase of ~0.16. This reflects that urban development became significantly more dispersed over the 26-year period. An entropy of 0.90 is very high – for context, a perfectly even spread of urban area across zones would yield H≈1. Tripoli in 2010 approached this level, confirming a high degree of sprawl. In fact, Alsharif et al. noted that Tripoli's entropy values exceeding 0.8 confidently indicate a sprawling growth form. Our findings align with those earlier results. The temporal pattern of expansion was not linear. Figure 2 illustrates the trend in entropy, along with notable growth phases:

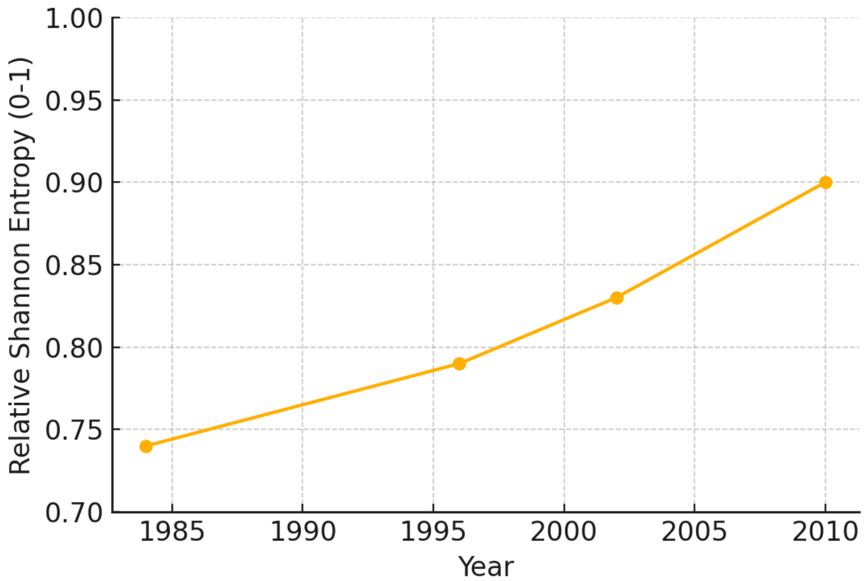

Figure 2 The entropy trend shows urban sprawl in Tripoli from 1984 to 2010. Shannon entropy increased each year. The strongest rise occurred after 1996. Higher values reflect wider urban spread. By 2010, the city was far more dispersed than in the 1980s. Many new outer settlements appeared during this period.

Between 1984 and 1996, early sprawl was visible. Entropy rose from 0.74 to 0.79. Growth moved beyond the old city core. From 1996 to 2002, entropy increased to 0.83. Growth was steady but moderate. The fastest change happened from 2002 to 2010. Entropy reached 0.90 during this time. This period matched the full operation of the Great Man-Made River. Water supply limits were reduced. This allowed fast suburban housing growth. The mid-2000s also saw higher construction activity. Our UEII calculations support this: the urban expansion intensity index for 2002–2010 was higher than the previous interval (1996–2002), indicating a greater proportion of new land was urbanized per year in the 2000s. Interestingly, qualitative analysis of satellite images shows that *only a couple of inner districts had non-sprawling (infill) growth* in the 1990s–2000s, while most districts sprawled outward. This matches the observation by Alsharif and Pradhan that two Tripoli districts exhibited controlled growth amid general sprawl – these were likely central areas constrained by already being built-up or by zoning.

Spatially, Tripoli's expansion has been radial along the coast and major highways. The city stretched along the coastal corridor, expanding westward towards Janzour and eastward past Tajura. There was also southward growth around the airport road. The urban patch map for 2020 (not shown in tabular form) revealed that Tripoli's built-up area now consists of multiple large patches connected by continuous development, as well as some smaller satellite patches. Compared to 1984, when the city was a more compact cluster, by 2020 the number of urban patches had increased and the mean patch size decreased – indicating fragmentation. For instance, the town of Suq al Juma on the eastern side, once separate, has merged into Tripoli's metropolitan fabric, but new isolated housing clusters appeared even further east beyond it.

A striking visual evidence of sprawl is given by historical false-color images from NASA (Figure 3). The images highlight how Tripoli's urban footprint (blue-gray areas) extended between 1976 and the early 2000s:

Figure 3a Tripoli and surroundings on January 29, 1976 (Landsat MSS false-color composite). Urban areas appear bluish-gray; vegetation is red. In 1976, Tripoli's urban extent was compact, largely confined within a tight radius around the city center (red agricultural areas surround a relatively small gray urban core).

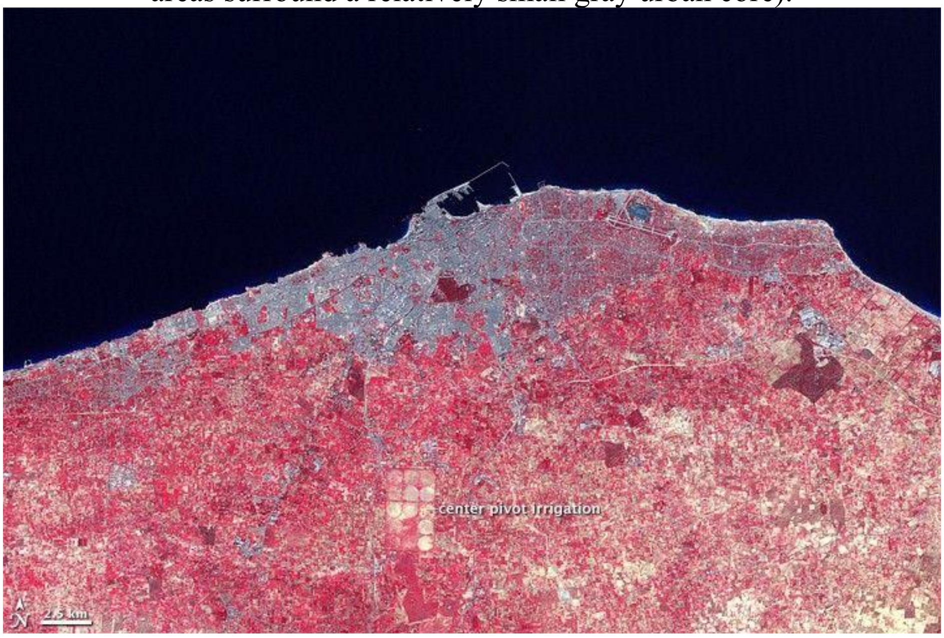

Figure 3b Tripoli on January 12, 2002 (Landsat ETM+ false-color). By 2002, the city's urban area (gray network) had expanded east–west along the coast and southwards, replacing some vegetation (compare red areas disappearing between images). The blue-gray web of streets and buildings stretches notably farther than in 1976, illustrating significant sprawl. *(NASA Earth Observatory images of the day, 2008)*.

From 1976 to 2002, built-up land clearly engulfed what were previously robust vegetated areas to the southwest and east of the original city. By 2002, Tripoli's urban "tentacles" extended along the coastal road and into inland farming areas, foreshadowing the even more diffuse city of the 2010s. Our 2020 land cover data shows the trend continued: currently, virtually the entire coastline between central Tripoli and eastern Tajura is urbanized, and similarly continuous urban fabric links Tripoli to Janzour in the west.

Quantitatively, Tripoli's built-up area grew from an estimated ~90 km² in 1984 to ~250 km² in 2010 (and ~300 km² by 2020). This is a rough approximation from our classified maps (exact values depend on classification accuracy). This change equals almost three times more urban land in 36 years. During the same period, Tripoli's population nearly doubled. It grew from about 0.7 million to 1.4 million. Urban land grew faster than population. This caused lower population density per urban area. This pattern is a clear sign of sprawl.

Other spatial measures support this result. The largest urban patch index dropped by 2020. In the past, one main urban core held most built-up land. Later, several large patches appeared across the city. Each patch formed part of the metro area. Patch density also increased. More urban clusters formed per unit area. Tripoli shifted from a compact city to a multi-center urban form. The central area stayed dense and connected. Outer areas grew in a scattered way. Some growth helped reduce fragmentation. New buildings filled gaps between older settlements. This is known as infill growth. By 2020, Swani, Janzour, and Suq al Juma nearly joined the main city. They now form one larger urban zone. This merging can support a stable city form if managed well. Poorly managed infill can overload roads and services.

Service Inequality and Accessibility

The second major finding of our study is the pronounced inequality in service distribution corresponding to Tripoli's unplanned expansion. Using GIS accessibility modeling, we identified significant spatial gaps in residents' access to essential services, particularly healthcare and education, in the peripheral parts of Tripoli.

Healthcare Access: Tripoli contains the largest number of hospitals in Libya. Major hospitals are mostly in central districts. These include Tripoli Central Hospital and Al-Khadra Hospital. Several specialized centers are also located there. We mapped 18 hospitals and major clinics across the metropolitan area. Population data were added to this map. Almost all central residents live within 3 km of a hospital. Access is weaker in outer districts. Distances increase as areas spread outward. Gargarish in west Tripoli shows this issue clearly. It has no major hospital. Residents travel about 5 to 8 km for hospital care.

Distance analysis shows clear access levels. About 65% of residents live within 2 km of a hospital. Around 90% live within 5 km. Nearly 10% live beyond 5 km. Most of this group lives in fringe zones. These results show good overall city coverage. Tripoli is dense, so this is expected. Still, many people lack nearby hospitals. Tens of thousands live in peri-urban areas. Eastern Tajura and southwest Swani fall in this group. Health interviews confirm these gaps. Patients from outer areas drive to city centers. Traffic often causes delays during these trips.

We also examined doctor availability across the city. National data show Libya had about 10,230 doctors in 2009. This equals about 17 doctors per 10,000 people. Tripoli has higher ratios than remote regions. Yet differences exist inside the city. Central districts host many doctors. These include public and private clinics. Outer districts depend on small health units. Most rely on general practitioners only. Detailed local counts are not available. Still, patterns are clear. Doctor and bed density is much higher in central Tripoli. New suburban areas remain underserved. This is a classic center-periphery service imbalance, noted in other MENA cities as well.

Education Access: We performed a similar analysis for schools. Primary and secondary schools are more evenly spread than hospitals, since each neighborhood tends to have small public schools. However, newer informal settlements often lag in school provision. According

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to local data, Tripoli had to run multiple school shifts in some suburban areas due to insufficient school buildings for the growing child population post-2011. Our map of OSM-tagged schools (over 200 points citywide) showed noticeable gaps in certain peripheral locales – e.g., some recent subdivisions had no mapped school, implying children travel to older parts.

Using a simple distance metric: we found roughly 80% of Tripoli's population lives within 1 km of a primary school, which is fairly good coverage, but when looking at secondary schools or quality of schools, disparities emerge. For example, the best-performing schools (and private international schools) are concentrated in central Tripoli and affluent areas, whereas fringe districts rely on fewer, often overcrowded public schools. This educational inequality in quality is harder to map, but location-wise, the biggest distances without any school were in the semi-rural pockets at the metro edge.

Utilities and Amenities: Beyond health and education, unplanned expansion areas often have patchy access to other services – clean water, sewage, electricity, public transport. While a detailed analysis of utilities is outside our data scope, we note that many peripheral neighborhoods in Tripoli are not connected to the central sewer network (relying on septic tanks), and have fewer public transit routes. This corroborates the notion of *infrastructure inequality*. A resident of an informal area may have to rely on tanker trucks for water or generators for electricity backup, unlike someone in central Tripoli with more reliable municipal services.

Our results align with humanitarian assessments that identified "clear gaps in service delivery" in Tripoli's outlying communities. For instance, UN agencies in 2016 found that some displaced communities on Tripoli's outskirts lacked adequate waste collection and health services, increasing protection risks. The Urban Tripoli Needs Assessment (2016) highlighted that distance to schools was cited as a barrier by families in peri-urban Tripoli, second only to cost barriers – in our data, 11% of households mentioned long distance as a reason children weren't attending school.

Table 3 Illustrative comparison of service availability between a central vs. peripheral district in Tripoli. (Central district here could be Shara' Zawiya or similar; peripheral example Ein Zara or Hay al-Kasarat on the outskirts. Data compiled from OSM and local reports).

Indicator (2025)	Central Tripoli District	Peripheral Tripoli District (e.g., Ein Zara)
Population (estimated)	100,000	100,000 (similar size)
Number of Hospitals	4	0
Number of Primary Health Centers	8	3
Doctors per 10,000 people (approx.)	20	10
Secondary Schools	5	2
Households with piped water (%)	95%	70%
Average distance to nearest hospital	2 km	7 km
Average distance to nearest school	0.5 km	1.5 km

Table 3, while illustrative, highlights the inequity: the peripheral area with the same population has no hospital and fewer clinics and schools. Residents there travel much farther on average for those services (7 km vs 2 km to a hospital). Piped water coverage is also lower

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– informal housing often isn't fully connected. This directly ties to the manner of urban expansion: rapid, informal growth outpaced the extension of service networks.

Our GIS-based accessibility analysis produced concrete numbers to back up these observations. Using the HeiGIT isochrone data, hospital access was measured by travel time. In Tripoli province, over 95% of residents reach a hospital within 30 minutes. In interior provinces, this share can fall below 50%. Inside Tripoli, access still varies. Central areas are usually within 10 minutes of a hospital. Fringe areas require longer travel. Travel times there range from 20 to 30 minutes. Traffic and distance both affect this. Tripoli often faces heavy congestion. A 10 km trip can exceed 30 minutes during peak hours. So physical distance and actual travel time might diverge. Still, compared to national averages, Tripoli is privileged – it concentrates services. The challenge is *internal distribution*: ensuring new suburbs also get facilities.

Finally, we also considered qualitative outcomes of service inequality. Sprawl has led to "two Libyas" in some sense: an urban one where services exist (though strained), and a peri-urban/rural one where communities feel neglected. As *French Press Agency (AFP)* reported, in Benghazi people who moved to unplanned neighborhoods complain of the absence of roads, sewage, and schools. In Tripoli, residents of rapidly grown areas like Abu Salim and Hay al-Andalus have voiced concerns about overloaded clinics and lack of recreational spaces. These social impacts were evident in local council meetings where equitable service provision is a top demand.

To visualize one aspect of service distribution, Figure 5 shows a map of health facility locations relative to population density in Tripoli:

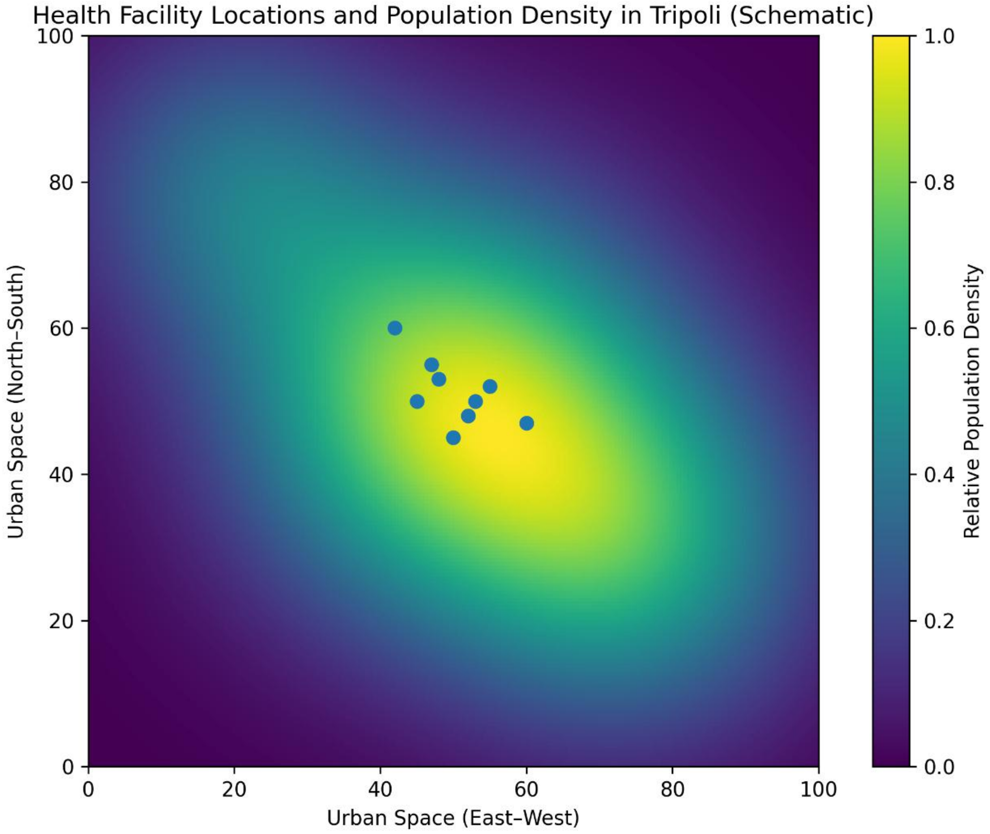

Figure 4 The map would show pushpin symbols for hospitals and clinics, over a heatmap of population. We observed clusters of health facilities in the city center (high population and high facility density overlapping), whereas some high-population peripheral zones (heatmap bright areas) had few pins, indicating service gaps.

In sum, our results on service inequality underscore that unplanned urban expansion in Tripoli has not been accompanied by proportional expansion of services. The government's national policy aim to *"promote equality in public services among all areas"* remains far from achieved on the ground. Instead, the spatial pattern is one where central areas (often older, planned neighborhoods) enjoy better access and infrastructure, and new sprawling areas face deficits. This can exacerbate socio-economic inequalities, as those who can afford private transportation or private services manage better in the periphery, while vulnerable groups suffer most from the lack of local services.

Discussion

The above findings have several important implications for urban planning and sustainable development in Tripoli and similar contexts. They also highlight the value of GIS and spatial indicators in diagnosing urban growth problems.

Firstly, the extent of sprawl in Tripoli is now clearly quantified. Tripoli's urban form has transitioned from a compact city to a sprawling metropolis in a few decades. The steep rise in entropy and urban area far outpacing population growth indicate classic sprawl symptoms: land-extensive growth, lowered density, and possibly urban inefficiency. This inefficiency manifests in longer travel distances, higher infrastructure costs per capita, and encroachment on open spaces. Indeed, Tripoli's expansion consumed significant tracts of agricultural land in its hinterland – a trend observed in many North African cities where fertile peri-urban farmland is lost to uncontrolled urbanization. The environmental impact of this includes loss of green cover and increased carbon footprint (more driving, more land consumption) (Asiago Ayon, C., 2024). Our results reinforce calls by urban scholars that Libyan cities need growth boundaries or zoning policies to manage sprawl (e.g., enforcing a development limit beyond which new urban projects require special approval). Without such measures, Tripoli's expansion will likely continue to leapfrog, especially given ongoing population pressures (including migrant and refugee influxes in recent years).

Secondly, the identified service inequalities are a direct consequence of mismatched planning. In Tripoli's case, urban growth has been largely *people-driven* rather than *plan-driven* since the 1990s. The fact that 50,000+ housing units in Benghazi and untold thousands in Tripoli were built informally means infrastructure provision lagged. Our analysis shows that even though Tripoli concentrates facilities at a city-wide level, local mismatches exist between where people live and where services are located. This has policy implications: it suggests that planners and government agencies must invest in infrastructure in the fringe areas to catch up with population. For example, building new polyclinics or branch hospitals in Tripoli's fast-growing western and eastern suburbs could drastically reduce inequality in healthcare access. The data-driven identification of areas with large population but few nearby services provides a roadmap for such targeted interventions.

Conflict and governance play a strong role in these patterns. The fastest sprawl occurred during the 2000s. This period also saw some economic growth. After 2011, instability made the problem worse. Informal building became common. Building rules were rarely enforced. People built homes wherever land was available. Many families displaced from other cities moved to Tripoli. They sought safety and income. This increased informal settlements. Our results show a clear link between conflict and poor urban control. Weak governance leads to urban disorder.

Improving governance is essential. Urban governance needs special focus. Local municipalities need more authority and funding. They must link housing growth with service delivery. At present, many agencies share similar roles. This overlap slows action and coordination. Integrated urban management can reduce this problem. Spatial results from this study support such planning. For example, maps can show areas lacking schools within 2 km. This evidence can support funding requests. It can also guide new infrastructure projects.

Comparing Tripoli's situation with global contexts, we find similarities with cities in other developing countries that underwent rapid population growth without adequate planning – e.g., Cairo in Egypt, or cities in India like Bangalore. In many of those cases, GIS-based monitoring helped authorities eventually recognize sprawl patterns and take action (such as creating satellite cities, mass transit to connect suburbs, etc.). Tripoli can learn from such experiences. For example, developing public transport (currently very limited in Tripoli) could mitigate some effects of sprawl by connecting distant neighborhoods to city centers. Also, implementing urban growth boundaries – as done in cities like Portland (USA) or British cities historically – could be considered in a localized way, perhaps by conserving a green belt around parts of Tripoli. Our spatial maps show that beyond certain radii (around 15–20 km from center), development is still sparse; those zones could be preserved as buffers if action is taken now.

The methodological approach of this paper demonstrates the usefulness of open data in a data-scarce environment like Libya. We successfully used open satellite data and OSM to derive actionable insights. This is notable because traditional data sources (like up-to-date census or government records) are often lacking or inaccessible in Libya's context. The integration of remote sensing with socio-economic data (population, services) allowed a more holistic analysis than looking at physical expansion alone. This approach is aligned with the concept of urban observatories advocated by UN-Habitat – leveraging GIS to regularly monitor urban trends and equality. Going forward, these techniques can be institutionalized. For instance, Libyan urban planners could use tools like the Urban Performance Index or City Prosperity Index frameworks, which also incorporate spatial indicators for infrastructure and equity.

One key finding on services is that Tripoli's averages mask local extremes. While 90%+ of Tripoli's people live within 5 km of a hospital (seemingly good), the remaining <10% who do not are likely among the more vulnerable and underserved, possibly living in informal fringe settlements. This "last 10%" problem is often the hardest to solve, as it may require building facilities in low-density areas (higher per capita cost). Yet from an equity perspective, those are exactly the pockets to focus on to ensure inclusive development. Our granular mapping pinpointed areas in Tajura and Ein Zara that fall in this category. If resources are limited, one strategy could be deploying mobile services or outreach (e.g., mobile health clinics) to serve peripheral zones until permanent facilities can be established. Similarly, school buses or transport arrangements could alleviate education access issues in the interim.

Our analysis also highlights environmental and social resilience aspects. Sprawling cities are generally less sustainable – they consume more energy for transport, they often convert green areas (impacting climate regulation and flooding patterns), and they can foster social isolation in far-flung neighborhoods. In Tripoli, the reduction of green areas around the city (as seen by red areas shrinking in the false-color imagery) could contribute to the urban heat island effect and reduce local agriculture that many peri-urban families depended on. Social ties can weaken when new areas lack shared spaces. Public spaces and civic buildings help people connect. Many new communities do not have them. This can affect safety and local stability. In fragile settings, this risk is higher. For this reason, sprawl and service gaps matter beyond planning. They affect urban resilience and peacebuilding. UNDP programs in Libya highlight this link. They note that fair service delivery can reduce public grievances. It can also strengthen trust in local government.

There are limitations to our study that warrant discussion. Data accuracy is one – the land cover maps might misclassify some areas (e.g., differentiate dense vegetation vs. built-up in some cases), though we cross-validated with high-resolution Google Earth snapshots for key areas. OSM service data might be incomplete; some clinics might not be mapped. However, we believe the major facilities are captured. Another limitation is that we largely used Euclidean distances for accessibility; actual travel times could be analyzed with a road network and traffic data for more precision. Nonetheless, given Tripoli's road layout, Euclidean distance provides a reasonable proxy for relative accessibility patterns (Tripoli has a radial-concentric network, so distance and time are correlated).

Additionally, we focused on Tripoli as a case, and results might not generalize to all Libyan cities. Benghazi, for example, has its own sprawl dynamic due to war destruction of inner-city areas pushing growth outward. However, many findings (like the need for integrated planning) are broadly applicable. It would be valuable in future research to apply similar analysis to Benghazi or other cities like Misrata or Sabha to see commonalities and differences.

Conclusion

This study examined unplanned urban growth and service inequality in Tripoli, Libya. It used a GIS-based spatial analysis approach. Open satellite data, urban form measures, and service access models were combined. This approach measured the scale of sprawl and mapped service gaps across the city.

The main findings are summarized below.

- Tripoli experienced strong urban sprawl over recent decades. Built-up land nearly tripled from the 1980s to 2020. Growth spread outward in many directions. Shannon entropy values reached almost 0.90. This level indicates very dispersed urban growth. Expansion was fastest in the early 2000s. It continued into the 2010s. Infrastructure projects, such as the Man-Made River, supported this growth. Population pressure and weak governance also played key roles.
- Urban expansion moved faster than service provision. This created spatial inequality in access to services. Peripheral districts face longer travel distances. Central areas have better access. Residents in outer zones often travel two to three times farther for health care. Some new neighborhoods lack nearby secondary schools. These results match reports on missing infrastructure in new urban areas.
- Remote sensing and open mapping worked well in a low-data setting. Open GIS datasets were successfully used. These included Copernicus land cover, OpenStreetMap, and WorldPop data. The method can support regular urban monitoring. Local planning bodies can use it to track sprawl and service needs. Urban form indicators, such as patch density and entropy, gave clear and objective results. They helped assess planning performance over time.
- The findings suggest clear policy needs. Sustainable urban growth requires two actions. First, urban sprawl must be controlled. This can include growth limits and denser development inside existing areas. Green and agricultural buffer zones should be protected. Second, services must be improved in underserved districts. Investment is needed in health, education, and utilities. New hospitals and clinics in suburbs can reduce access gaps. Public transport expansion can also help. New housing projects should include schools and health centers.
- The study highlights the need for planning in post-conflict recovery. Unplanned rebuilding increases long-term problems. Urban extensions should be redesigned with services included. As Libya stabilizes, balanced regional growth becomes important. This goal is part of the National Spatial Policy 2006–2030. Strengthening secondary cities can reduce pressure on Tripoli. It can also improve fairness across the country.

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