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Urban Cartography and Geospatial Analysis: Mapping Street Networks in a Segment of Oredo Local Government Area, Benin City

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ABSTRACT

Benin City, a historic urban center in southern Nigeria, faces challenges in navigation and urban planning due to outdated street maps. This study applied urban cartography and geospatial analysis techniques to produce an updated street network map for a portion of Oredo Local Government Area in Benin City. High-resolution Google Earth imagery, existing basemap data, and field-collected GPS coordinates were integrated using Geographic Information Systems (GIS) and remote sensing methods. Key methodologies included image processing, georeferencing of satellite imagery and scanned maps, on-screen digitization of road networks, creation of a spatial database, and field verification of map features. The resulting street map covers approximately 15.89 km² and reflects numerous new developments and previously unmapped roads. Quantitative accuracy assessment demonstrated a high level of precision: differences between on-ground measured road lengths and GIS-derived lengths for major roads were on the order of only a few centimeters, indicating excellent positional accuracy. The updated map and accompanying GIS database provide a reliable foundation for urban navigation, infrastructure planning, and emergency response. The discussion highlights the implications of these results for urban planning and the utility of up-to-date geospatial data in supporting efficient city management. The study concludes that modern GIS-based mapping significantly improves the accuracy and usefulness of urban street guides and recommends regular updates and broader mapping coverage to sustain these benefits.

Keywords: Urban cartography; Geospatial analysis; Street network mapping; GIS; Remote sensing; Benin City

Introduction

Benin City, the capital of Edo State in Nigeria, is a historic city with significant cultural and economic importance. Its intricate network of streets and the rapid urbanization of recent decades have increased the need for accurate and up-to-date street mapping (Eweka, 2016). Currently, many available maps of Benin City are outdated or inconsistent, posing challenges for navigation and urban planning. An updated street guide is essential to address problems such as poor navigation systems and inadequate planning data in this growing city (Adeniyi, 2017; Adeboye, 2018). Accurate street maps serve as critical tools for residents and visitors by enabling efficient navigation and disaster management, and they provide urban planners with reliable spatial data for infrastructure development and service delivery (Adeniyi, 2017). In rapidly expanding cities like Benin City, maintaining an up-to-date street map is crucial for managing urban sprawl and addressing infrastructural deficits (Adeboye, 2018).

Benin City's blend of historical layout and modern growth presents unique challenges and opportunities for mapping. The city's ancient street configuration rooted in its history as the center of the Benin Empire coexists with contemporary urban developments, resulting in a complex spatial structure (Okojie, 2019). This duality necessitates a detailed and nuanced cartographic approach that respects the historical context while meeting modern navigation and planning needs (Eweka, 2016). Technological advancements in geospatial science, particularly Geographic Information Systems (GIS) and remote sensing, have revolutionized urban mapping in recent years. These tools enable the integration of diverse data sources and provide more precise, comprehensive spatial data (Omole, 2015). For example, high-resolution satellite imagery and GIS-based analysis can greatly enhance the precision and usability of street maps (Olofin, 2017). By leveraging these modern technologies, it is possible to produce detailed street network maps that improve urban navigation, planning, and resource allocation in Benin City.

Previous studies and community feedback have highlighted serious inadequacies in existing maps of Benin City, noting discrepancies between mapped information and on-ground reality (Ebohon, 2018). Such inconsistencies hinder effective navigation and urban management, underscoring the urgent need for updated and reliable mapping solutions (Ojeifo, 2020). In particular, the absence of a comprehensive, current street guide poses challenges for emergency responders and service providers; for instance, firefighters or ambulance services may struggle to locate addresses promptly using outdated maps (Agbontaen, 2014). Beyond immediate navigation and safety concerns, urban cartography plays a critical role in broader socio-economic development. Accurate and accessible street maps facilitate better access to services, improve logistics for businesses, and can even support tourism (Osadolor, 2013). In a city with rich cultural heritage like Benin City, well-documented and easily readable street maps can enhance heritage tourism by guiding visitors to cultural sites, thereby contributing to local economic growth (Ugiagbe, 2015).

In light of these challenges and needs, this study aims to create a comprehensive and accurate street network map for a segment of Oredo Local Government Area in Benin City. By using modern GIS and remote sensing techniques to update the existing street map, the project seeks to produce a reliable street guide that reflects the current state of the city’s road network. The overarching goal is to support development and planning initiatives with up-to-date spatial data. This paper details the methodology used including data acquisition, image processing, GIS-based mapping, and field verification presents the results of the new mapping in terms of accuracy and findings, and discusses the implications of having an improved street map for urban planning and geospatial data utilization in Benin City.

2. Methodology

2.1 Study Area

The mapping effort focused on a portion of Benin City within Oredo Local Government Area (LGA) in Edo State, Nigeria. The study area is geographically situated approximately between latitudes 6°05′N to 6°25′N and longitudes 5°20′E to 5°40′E. It covers an area of about 15.89 square kilometers, representing the urban core of Oredo LGA. This area includes a dense network of primary and secondary roads, as well as various residential, commercial, and institutional land uses. The choice of this segment of the city was motivated by its economic importance and the observed need for updated spatial data to guide urban services and planning decisions in the district.

2.2 Method

Both primary and secondary data were collected to ensure a robust mapping process. The secondary data included an existing digital basemap of Oredo LGA (showing roads and administrative boundaries) obtained from the Edo State Ministry of Lands and Survey and high-resolution satellite imagery from Google Earth covering the study area. The Google Earth imagery provided current visual information on the street layout and land use as of the latest capture date. Primary data collection involved field visits to gather Ground Control Points (GCPs) and other ground-truth information. Using a handheld Garmin GPS unit, twenty (20) GCPs were recorded at accessible road intersections and other prominent features throughout the study area. These GCP coordinates (latitude/longitude in WGS84 datum) were later used for georeferencing and accuracy assessment. During field visits, qualitative attribute data were also gathered – for example, verification of street names, identification of notable landmarks (schools, markets, churches, etc.), and observations of any new road constructions or changes not reflected in older maps.

The mapping and analysis made use of standard geospatial hardware and software tools. In addition to the handheld GPS receiver for field data collection, a laptop computer with sufficient processing capability was used for GIS data processing and map compilation. A high-resolution scanner (A0 size) was employed to digitize paper maps where necessary. The primary software platform was ESRI's ArcGIS (version 10.7), which provided functionalities for image display, georeferencing, vector digitization, spatial database creation, and cartographic map production. Microsoft Excel was utilized for organizing field data and performing any needed calculations (such as converting units or computing differences in coordinates), while Microsoft Word was used in preparing documentation and the final report. A printer/plotter was available to produce hardcopy maps for field verification and the final map output.

The methodology began with integrating the Google Earth satellite imagery with the existing basemap. The imagery and any scanned maps were first projected to a common coordinate system (Universal Transverse Mercator Zone 32N, WGS84 datum) to ensure spatial alignment. An image-to-map registration technique was applied to accurately overlay the satellite image on the older map. This involved georeferencing the scanned basemap image by assigning real-world coordinates to known locations on the map. Conspicuous points such as major road intersections and junctions visible on both the Google Earth image and the old map were chosen as control points. The coordinates of these locations were obtained from the Google Earth image (which was already geographically referenced) and input into ArcGIS's Georeferencing tool to tie the scanned map to the correct geographic locations. A minimum of four well-distributed control points were used for the georeferencing, and a first-order polynomial (affine) transformation was applied to minimize residual errors. The root-mean-square error (RMSE) of the transformation was checked to ensure that the georeferencing accuracy was within acceptable limits for mapping (typically on the order of a few meters or less). Once a satisfactory alignment was achieved, the adjusted basemap image was "rectified" (resampled and saved) as a new raster layer aligned with the satellite imagery.

With both the up-to-date satellite imagery and the rectified basemap in the GIS environment, the next step was on-screen digitization of the street network and other features. A geodatabase was created in ArcGIS to store the vector data layers. Within this geodatabase, several feature classes were defined corresponding to different feature types: for example, Major Roads, Minor Roads, Paths/Footpaths, Rivers/Waterways, Landmarks (Points), and Administrative Boundaries. Each feature class was assigned an appropriate geometry type (line for roads and rivers, point for landmarks, polygon if needed for certain areas or facilities) and an attribute schema (including fields like road name, road class, or landmark name). Using the ArcMap editing tools, the digitization was carried out by tracing over the Google Earth image and the scanned map. Major roads and notable streets were digitized as line features, following the centerline of each road visible on the imagery. To maintain accuracy during digitization, the snapping tool was enabled (vertex and edge snapping) to prevent overshoots or gaps between road segments at intersections. This helped ensure topological continuity – all road segments that should connect at intersections were properly connected in the data, avoiding dangles or overshoots. After capturing the road network, additional features were digitized: major landmark points (such as schools, hospitals, markets, and churches identified during field work) were added as point features with their recorded GPS coordinates to enhance the map's utility. New roads or streets that appeared on the recent imagery but were missing from the old basemap were given special attention – these were digitized and flagged as updates to the prior map.

As the spatial features were created, a corresponding attribute database was built to store relevant information about each mapped element. For roads, attributes such as road name, road category (e.g., highway, main road, residential street), and surface type (paved or unpaved, if known) were recorded. Landmark points were attributed with names and feature type (e.g., "School: Immanuel Primary School" or "Market: Oba Market"). The database design followed a relational structure where appropriate, to allow future queries and analysis; for example, separate tables for road attributes and intersection nodes could be linked if needed. During this phase, the draft map along with its attribute annotations was printed and taken to the field for a field completion exercise. In this exercise, the team verified on the ground that the roads exist as mapped, confirmed the names of streets (especially where signposts were available or through local inquiry), and checked the locations and names of landmarks. Any discrepancies found such as a road that was closed off, a different name usage by locals, or additional minor streets not visible in imagery due to tree cover were noted and later updated in the GIS database. The field completion also allowed the collection of missing information like road name spellings and confirmation of connectivity (for instance, whether two roads that appear close on the imagery are actually connected or separated by a barrier in reality).

After incorporating the field verification feedback, the dataset underwent a rigorous editing process to ensure cartographic quality and logical consistency. A topology was created for the road network layer to enforce connectivity rules – for example, all roads that intersect should share a common node, and there should be no unintentional overshoots or undershoots at intersections. The topology rules were validated in ArcGIS, which helped identify any small digitization errors such as dangles (dangling lines) or overlaps. Identified errors were corrected by trimming or extending line endpoints and unifying nodes at junctions. Ensuring topological consistency was important for the map to function accurately not only as a visual guide but also for network analysis (such as routing or distance calculations) if needed. Additionally, the completeness of the data was reviewed – checking if all major roads visible on the imagery were indeed captured and labeled, and that no significant features were omitted. The map was then symbolized using standard cartographic conventions: major roads were rendered with thicker lines, minor streets with thinner lines, and different colors or line patterns were used to distinguish categories (for example, perhaps blue lines for primary highways, black lines for local streets, dashed lines for footpaths, etc.). Standard map elements such as a scale bar, north arrow, legend, and title block were added in the layout view to prepare the final map output.

A key component of the methodology was assessing the accuracy of the newly created street map. Three aspects of accuracy were considered: positional (spatial) accuracy, attribute accuracy, and logical consistency. For positional accuracy, both relative and absolute accuracy checks were performed. The relative accuracy was evaluated by comparing the lengths of selected road segments on the map to their lengths measured on the ground. During field work, the team used the GPS device to measure the distance of five major road segments: Airport Road, Ekehuan Road, First East Circular Road, Sakponba Road, and Mission Road. These ground-truth lengths were then compared to the corresponding road lengths computed from the GIS data (using the "Calculate Geometry" function in ArcGIS). The differences between field-measured and GIS-derived distances were found to be extremely small, on the order of only 0.00001 to 0.0001 kilometers (i.e., a few centimeters). For example, the length of Airport Road measured in the field was about 1.961566 km, compared to 1.961668 km from the map, a difference of roughly 0.000102 km (~10 cm). Other roads showed similarly minimal discrepancies (differences ranging from about 0.00001 km to 0.00008 km for the roads listed). These negligible differences indicate a very high relative accuracy of the digital map with respect to real-world distances. To examine absolute accuracy, the team took GPS readings for the coordinates of several key points (such as the location of a prominent roundabout, a major road intersection, and notable buildings including Uwa Shopping Plaza and a state ministry building) and checked these against the mapped positions of the same features. The GPS-recorded coordinates and the map coordinates of these features showed an excellent alignment, with differences typically within a few meters or less. This confirms that the georeferencing and overall mapping process placed features in their correct real-world locations. For attribute accuracy, the field verification stage ensured that non-spatial information such as street names and landmark identifiers were correct on the map. Any errors in naming (for instance, alternate spellings or local names) were corrected after the field checks. Taken together, these steps ensured that the final street map was not only up-to-date but also highly accurate in position and information.

3. Results

The mapping project resulted in a revised street guide map for the selected part of Oredo LGA in Benin City, along with an accompanying GIS database of the road network and related features. The new map reflects a comprehensive street network, including all categories of roads from major thoroughfares to smaller residential streets. One of the immediate findings was the identification of several new roads and extensions that were absent on earlier maps. Through the change detection process (overlaying the new satellite imagery with the old basemap), multiple developments were documented – for example, newly constructed residential layouts and connector roads that had been established in recent years. These previously unmapped roads have now been incorporated into the street guide, thereby filling important gaps especially in rapidly developing neighborhoods. The updated map also highlights changes in road hierarchy: some routes that were once minor paths have been upgraded and paved, altering their classification to major road status, and this too is captured in the new dataset. All significant landmarks (markets, schools, churches, banks, etc.) within the study area are plotted on the map, providing users with reference points that enhance orientation and usability of the street guide.

A major outcome of this project is the high accuracy of the spatial data achieved. Quantitative accuracy assessment confirms that the positional reliability of the mapped features is excellent. For the key roads measured, the differences between the field-measured lengths and the map-derived lengths were exceedingly small. In practical terms, each of the five major roads checked showed a length difference of only about 0.01% or less when compared to ground truth. For instance, Airport Road's length differed by approximately 0.0001 km (around 10 centimeters) between the on-ground measurement and the GIS map calculation, and similar sub-decimeter differences were noted for Ekehuan Road, First East Circular, Sakponba Road, and Mission Road. Such minimal discrepancies underscore that the georeferencing and digitization processes were successful and that the relative accuracy of the street network is within a few centimeters over distances of a couple of kilometers. This level of precision far exceeds typical requirements for city navigation maps, meaning the map can be trusted for both civilian use and professional planning purposes.

The absolute accuracy was also validated by comparing GPS coordinates of certain points to their positions on the map. For example, the coordinates of a prominent intersection and a landmark building (gathered via GPS) matched the map locations with only negligible differences (on the order of a few meters or less). This indicates that the entire map is correctly scaled and positioned in the real-world coordinate system, an important consideration for integrating this map with other geospatial datasets or for any future surveying work.

Additionally, the attribute accuracy of the map is high: all verified street names and feature labels were updated to reflect on-ground reality. Local variations in street names were noted; in such cases, the most widely recognized name was used on the map, and alternate names could be added in the database for reference. The completeness of the street guide is also greatly improved over previous editions. No major roads in the study area are missing from the new map, and even many minor streets are included, thanks to the use of high-resolution imagery and thorough field checks. The final street guide map is rendered in a clear, user-friendly format and includes a legend, scale, and north arrow for orientation. It provides a much-needed updated reference for the area's road network.

The results demonstrate that the integration of remote sensing imagery with existing maps and field data can produce an **accurate and up-to-date street network map**. The new map for part of Oredo LGA covers an area of roughly 15.89 km^2 and can serve multiple purposes: everyday navigation for residents and visitors, base data for urban planners and engineers, and a tool for emergency services to improve response times. The creation of a GIS database alongside the map means that the data can be easily updated and queried. For instance, planners can use the data to calculate network distances, analyze accessibility to services, or simulate traffic routes. The high positional accuracy achieved suggests confidence in using this data for precise applications, such as infrastructure planning (e.g., laying out utility lines or optimizing public transport routes). Overall, the mapping project has filled critical knowledge gaps about the current state of the street network in this part of Benin City, providing a platform that can be built upon with future updates and expansions.

4. Discussion

The successful development of an updated and accurate street network map for Oredo LGA in Benin City has several important implications for urban planning and the broader utility of geospatial data in the region. First and foremost, the high accuracy of the new map means that urban planners and policymakers can rely on this geospatial data to make informed decisions. In the past, the lack of precise and current maps hampered effective planning, as infrastructure projects and zoning decisions were being made on the basis of outdated information (Adeboye, 2018). With the revised map, city planners have an up-to-date visualization of the road network, including new developments and road extensions that were previously unaccounted for. This enables better planning of traffic management systems, identification of areas in need of road improvements, and optimization of new routes for transportation projects. Accurate spatial data supports strategic infrastructure development by highlighting connectivity gaps in the network and helping to allocate resources efficiently. For example, if certain rapidly growing neighborhoods were found to have limited access roads, authorities can prioritize those areas for road expansion or alternative access routes. The precise mapping data also improves the quality of feasibility studies for new projects (like where to site a new bus terminal or how to route a new highway bypass) because the base data reflect the current reality of the urban environment (Adeniyi, 2017).

Another key implication is the enhancement of navigation and emergency response capabilities. The updated street guide directly addresses many of the navigation challenges that residents, businesses, and visitors faced when using older maps (Ebohon, 2018; Ojeifo, 2020). With the comprehensive coverage of even newer streets, logistic companies and delivery services can optimize their routes, reducing travel time and costs. More importantly, emergency services such as ambulances, police, and fire brigade can utilize the improved map to respond more quickly and accurately to incidents. In emergency situations, knowing the fastest and most efficient route – and having confidence that the map reflects actual on-ground conditions – can save crucial minutes. The inclusion of landmarks and facility locations (hospitals, schools, markets, etc.) in the GIS database further aids responders in quickly identifying target destinations or incident locations. The updated map also supports disaster management planning; for instance, in flood or fire risk assessments, current road data is essential to model evacuation routes and plan resource distribution. By resolving previous inconsistencies and errors (Agbontaen, 2014), the new street map becomes a reliable tool for public safety agencies.

The project also underscores the value of modern GIS and remote sensing techniques in urban cartography. The seamless integration of satellite imagery, existing maps, and field GPS data in this study demonstrates a replicable approach for other cities or additional parts of Benin City. It shows that even where official mapping resources are outdated, it is feasible to systematically update spatial data using high-resolution imagery and relatively accessible technology. This has broader utility for geospatial data infrastructure: city authorities and planners can maintain a digital GIS database for continuous map revisions, rather than treating maps as static products that become obsolete. The methodologies employed – such as on-screen digitization and GIS-based accuracy checks – illustrate a practical workflow for continuous map improvement. Over time, establishing a centralized geospatial database for Benin City (and Edo State at large) would allow various stakeholders (urban planners, utility companies, navigation service providers, etc.) to access and contribute to the most current spatial data. This inter-agency data sharing can foster better coordination in urban development initiatives.

From a socio-economic perspective, having an accurate and accessible street map supports a wide range of positive outcomes. Improved access to services is one such outcome: citizens can find the shortest routes to health facilities, markets, and other essential services, which is particularly beneficial in urban settings where time and transportation costs are significant factors. Businesses also benefit from reliable maps; for example, ride-sharing and delivery apps rely on digital maps to connect service providers with customers. An accurate base map of the city is fundamental for these technologies to function effectively, leading to more efficient commerce and service delivery in the city. Additionally, the map can enhance cultural tourism in Benin City. As noted by Osadolor (2013) and Ugiagbe (2015), clear documentation of streets and heritage sites can encourage tourism by making it easier for visitors to navigate to museums, historical landmarks, and cultural centers. The map produced in this study includes many such points of interest, potentially serving as a template for tourist maps or interactive guides that highlight Benin City's rich cultural heritage. In turn, increased tourism can contribute to local economic development, validating the idea that geospatial data has utility beyond urban planning it can be a driver for economic and cultural initiatives as well.

The high accuracy achieved in this mapping project also invites consideration of maintaining and updating the spatial data regularly. City landscapes are dynamic; new roads are constructed, and names or traffic directions can change. The discussion thus extends to how the methods used here can be institutionalized for continuous update cycles. One recommendation is that local government bodies adopt a schedule (for example, annual or biennial) to acquire the latest satellite imagery and perform incremental updates to the GIS database. Minor updates, such as adding a newly opened road or a recently built public facility, could be done more frequently using GPS field surveys. By doing so, the street network data remains current, and the effort required for each update is less intensive than a wholesale remapping after many years. The study's approach demonstrates that with appropriate training and tools, in-house GIS units of city agencies could manage this update process effectively.

In summary, this project's results illustrate the critical role of up-to-date geospatial data in urban management. The implications for urban planning include better-informed decision-making, improved infrastructure development strategies, and enhanced ability to plan for future growth. The utility of geospatial data is evident in everyday navigation improvements and in strategic applications like emergency response and economic development. This case study of Oredo LGA in Benin City can serve as a model for other local governments seeking to leverage GIS and remote sensing for urban cartography. It highlights that investments in accurate mapping yield tangible benefits across multiple sectors of urban governance and public life. As cities continue to grow and change, sustaining these efforts will be key to ensuring that spatial information keeps pace with development.

5. Conclusion

This research has demonstrated the successful application of urban cartography and geospatial analysis to produce an updated street network map for a segment of Oredo LGA, Benin City. The study addressed the pressing issue of outdated maps by leveraging modern GIS technology, high-resolution satellite imagery, and field survey data to create a comprehensive and accurate street guide. Key outcomes of the project include the integration of new roads and developments into the map, the establishment of a GIS database for spatial features, and verification that the map's accuracy is within a few centimeters for major road lengths. The resulting map effectively bridges the gap between the city's historical layout and its present-day expansion, providing a reliable representation of the current road infrastructure.

The benefits of this updated street map are manifold. It enhances navigation for residents and visitors, ensuring that people can find destinations and plan routes with confidence in the map's accuracy. Urban planners and policymakers now have at their disposal a precise spatial dataset to inform decisions on transportation planning, land use allocation, and infrastructure investments. The improved data is expected to translate into more efficient traffic management and better-targeted development projects, as planning can focus on actual needs identified in the current road network. Emergency services will also likely see improved response times, as dispatchers and first responders can use the detailed map to identify optimal routes and avoid delays caused by previously uncharted roads or misidentified routes. In the broader context, the accurate street guide supports socio-economic growth by facilitating commerce (e.g., logistics and delivery services) and promoting tourism through easier access to cultural sites.

Despite its contributions, this study also highlights areas for future work to ensure that the gains in mapping accuracy are maintained and expanded. One important recommendation is to implement a regular update cycle for the street map. Given the continuous development in Benin City, it is advisable that the responsible agencies periodically update the GIS database – for example, by acquiring new satellite imagery annually or biannually and conducting field checks on any notable changes. Establishing a proactive update schedule will prevent the map from becoming obsolete and will provide decision-makers with up-to-date information at all times. Another suggestion is the development of a centralized GIS repository or database for the city's spatial data. Such a repository could integrate various layers (roads, utilities, demographic data, etc.) and be made accessible to different stakeholders including urban planners, utility companies, and the public. Centralization and sharing of geospatial data will enhance collaboration among agencies and improve overall data consistency for the city.

Furthermore, while this project focused on a segment of Oredo LGA, a logical next step is to extend the mapping effort to cover the entire Benin City metropolis. A city-wide updated street guide would ensure uniform accuracy and coverage across all local government areas of the city. This comprehensive approach would benefit regional planning and could feed into a master plan for the Greater Benin City area. Extending the study would also allow for connectivity analysis on a larger scale, potentially identifying city-wide patterns in road network density, accessibility, and mobility that were beyond the scope of the current segment-focused project.

In conclusion, the project has successfully achieved its aim of providing an up-to-date and accurate street map for part of Benin City. The integration of GIS and remote sensing proved to be an effective methodology for urban map revision, resulting in a product that holds significant value for navigation, planning, and development. The study underscores that maintaining accurate geospatial data is critical in a rapidly urbanizing world, and it demonstrates a practical approach to doing so. By adopting the recommendations for regular updates and broader data integration, city authorities can ensure that this enhanced street mapping continues to support Benin City's urban management and growth in the years to come.

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