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Research Article

Research on building urban technical infrastructure database based on national geographic database at scale 1:2000 combined with other information sources - Van Chuong Ward, Dong Da District, Hanoi City

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Abstract: Geographic Information Systems (GIS) provide numerous benefits, including the ability to collect, store, manage, analyze, display, and update data while integrating diverse data types from multiple sources. Specifically, the urban technical infrastructure database serves as an information system designed to manage, store, and utilize data related to urban infrastructure works. This study aims to build an urban technical infrastructure database for Van Chuong Ward, Dong Da District, Hanoi. The research methodology includes extracting relevant databases, collecting and standardizing records and documents, conducting field investigations, and editing maps. The results consist of database groups extracted from the national geographic database, analyzed from related records and documents, supplemented through fieldwork, and compiled into a comprehensive urban technical infrastructure database. This study will be highly valuable for urban infrastructure management, supporting strict oversight, public asset preservation, and effective urban planning.

Keywords: Urban infrastructure database; National geographic database; Fieldwork, Van Chuong, Hanoi.

1. Introduction

Our world is continuously evolving, driven by remarkable advancements in science and technology over recent years. The advent of Industry 4.0 technology has marked the beginning of a new era, leveraging its potential to drive significant breakthroughs in both technology and human life. Currently, geographic technologies advancing rapidly and are widely applied across diverse fields, especially in research and socio-economic management [1–2]. A significant number of these applications are built on the geographic information system (GIS) technology platform, with GIS systems being standardized in accordance with current regulations during their development. GIS has become a prominent scientific field, garnering significant interest in various research and application areas worldwide. It plays a crucial role within the information technology ecosystem and serves as an indispensable tool for supporting critical decision-making processes. GIS technology facilitates the collection, storage, analysis, management, visualization, and updating of data associated with geographic locations. It also integrates and links diverse datasets, including spatial objects, object-specific information, and socio-economic data [3–4]. By processing and connecting these datasets to real-world spatial objects through a spatial coordinate system, GIS transforms raw data into valuable and actionable insights. With its remarkable capabilities, GIS has been widely developed and applied across numerous domains, including socio-economics, security and defense, environmental management, transportation, and natural resource exploitation.

An urban technical infrastructure database is a systematically organized digital system designed to store, manage, and analyze data related to a city's fundamental infrastructure components, including transportation networks, water supply systems, wastewater management, electricity distribution, communication networks, and public facilities [5]. It integrates various data sources, including Geographic Information System (GIS), remote sensing, Building Information Modeling (BIM), Internet of Things (IoT) sensors, and survey data, to support urban planning, management, and decision-making [6]. By providing accurate, real-time, and comprehensive information on urban infrastructure, these databases contribute to enhancing the efficiency, sustainability, and resilience of urban development.

The national geographic database is essential for numerous applications, including urban management and planning, improving public services, driving economic development, managing resources, protecting the environment, and supporting disaster prevention and risk management [7]. It also contributes to research, education, and improving the overall quality of life for people. In particular, this database supports urban development planning, the construction of residential areas, and the design of technical infrastructure systems, all aimed at creating a better living environment. Furthermore, it enables effective natural resource management, environmental monitoring, and ensures a balanced alignment between national and community interests [8].

Numerous studies worldwide have focused on urban infrastructure databases [9–13]. For example, the study [9] introduced GUIDES, an innovative data management and transformation framework for urban underground infrastructure systems. This framework enables city managers, workers, contractors, and other users to query digitized and integrated data, facilitating smarter decision-making.

Another study focused on developing a system for collecting, preprocessing, and presenting infrastructure data, creating an ecosystem for working with online urban spatial information applicable to any region. The study detailed the implementation of fundamental software components for managing urban infrastructure data, addressing challenges in aggregation and storage organization. Additionally, it proposed an approach to systematically accumulate and preprocess data by parallelizing the parsing of open network sources, employing proxy protection to ensure successful updates, and extracting structured descriptions of proposed infrastructure objects [10].

The study [11] explored the development of general urban analysis tools capable of adapting to various data formats, addressing a challenge that has not been widely tackled in practice. The study introduced an innovative system called the Urban Data Analysis Infrastructure (UADI), which leverages advanced technology to integrate heterogeneous datasets. The system employs a two-level mapping method to integrate heterogeneous datasets into a unified structure.

In another study, a systematic approach was proposed to develop a 3D spatiotemporal morphological database for urban green infrastructure (UGI). This database incorporates comprehensive information describing the shape of UGI in the horizontal and vertical planes, as well as its temporal changes. It calculates and incorporates three types of morphological parameters, which can be linked to simulation programs and analytical models, supporting sustainable urban design and facilitating research on various topics [12]. The study [13] initiated the National Urban Database and Access Portal Tool (NUDAPT) project, which focuses on generating and providing gridded urban canopy parameter fields. This project enhances urban simulations by incorporating new and detailed high-resolution data on buildings, vegetation, and land use. These parameters improve the accuracy of physics-based urban modeling.

Several studies on urban technical infrastructure databases have been published in Vietnam [14–18]. One study created a 3D geospatial dataset for the urban green tree system in Ha Long city's coastal area by integrating modern geospatial technologies. The dataset was developed using low-cost drone technology and widely used software tools such as Excel, ArcMap, Sketchup, and FME [14]. In another study, Nguyen and her research team developed a current and future 3D-GIS map for Hai Chau district in Da Nang city. This research applied GIS, GPS, and remote sensing (RS) technologies, along with advancements in 3D-GIS, to manage urban areas in three dimensions. The system provides powerful visualization and management features, allowing flexible information sharing and creating a breakthrough in spatial management and urban planning. This approach enables managers to visually observe each area from multiple perspectives, providing detailed insights for decision-making [15].

The next group of researchers used GIS to create a spatial database in the ESRI Personal Geodatabase format, integrating a raster dataset (DigitalGlobe images) divided into 34 vector data layers. This database focused on the water supply infrastructure system in the inner-city districts of Can Tho [16]. Danilov's research considers the problem of collecting data on the state of urban infrastructure and applying spatial data analysis to solve problems of urban territory management and urban planning [17]. In another study, [18] explored the creation of underground construction maps, methods for displaying underground infrastructure objects, and the development of an underground construction database. This research aimed to address the urgent need for managing and exploiting underground infrastructures in urban areas.

The rapid development of infrastructure, economy, and tourism, coupled with the surge in construction investment, has caused significant changes to the technical infrastructure of Hanoi. Specifically, this study focuses on Van Chuong Ward, located in Dong Da District, Hanoi. This area is densely populated, with a high population density, and its infrastructure is rapidly evolving in line with modern development trends. Consequently, state management agencies must continuously innovate and improve their management capabilities to meet the increasing demands and keep up with the region's development.

Key sectors such as urban landscaping, lighting, water supply and drainage, and green spaces particularly require modern and advanced management to swiftly adapt to changing conditions. Coordinated management and investment across these areas will improve efficiency, optimize resources, and foster unity for sustainable urban development. To achieve this, establishing an accurate, synchronized, detailed, and continuously updated spatial data platform is crucial for effective utilization. Urban spatial data serves as the core of smart city solutions, supporting various sectors such as healthcare, transportation, education, and tourism.

The results of this research will provide practical contributions to local managers and relevant departments, enabling them to manage, utilize, and effectively exploit core urban technical infrastructure data layers in a coordinated manner. Additionally, it will support the ongoing development and enhancement of these data layers in the research area. From a scientific perspective, the findings will contribute to the research and development of processes and urban technical infrastructure data layers, offering a framework that can be appropriately applied to other areas within Hanoi and other regions across Vietnam.

2. Study area and process

2.1. Study area

Van Chuong is a ward situated in Dong Da District, Hanoi, Vietnam (Figure 1). It is bordered to the north by Van Mieu and Quoc Tu Giam wards, to the west by Hang Bot and Tho Quan wards, and to the south and east by Kham Thien ward. Van Chuong Ward has a total area of 0.33 square kilometers and a population of 16,619 residents, resulting in a population density of approximately 50,360 people per square kilometer [19]. Van Chuong Ward is served by major traffic routes, including Tran Quy Cap and Quoc Tu Giam streets. Additionally, near the ward's boundary, Ton Duc Thang and Le Duan streets intersect with Ring Road 2, which spans multiple districts such as Long Bien, Hai Ba Trung, Thanh Xuan, Dong Da, Ba Dinh, Cau Giay, Tay Ho, and Dong Anh, and is located approximately 4.5 km from the ward's center. Ring Road 3, which connects districts including Dong Anh, Bac Tu Liem, Nam Tu Liem, Cau Giay, Thanh Xuan, Thanh Tri, Hoang Mai, Long Bien, and Gia Lam, is situated around 6 km from the ward. The center of Van Chuong Ward is approximately 4 km from Hanoi's city center (Hoan Kiem Lake), a distance that typically requires about 15 minutes by car. Additionally, Noi Bai International Airport is located approximately 27 km away, with an estimated travel time of around 40 minutes by car.

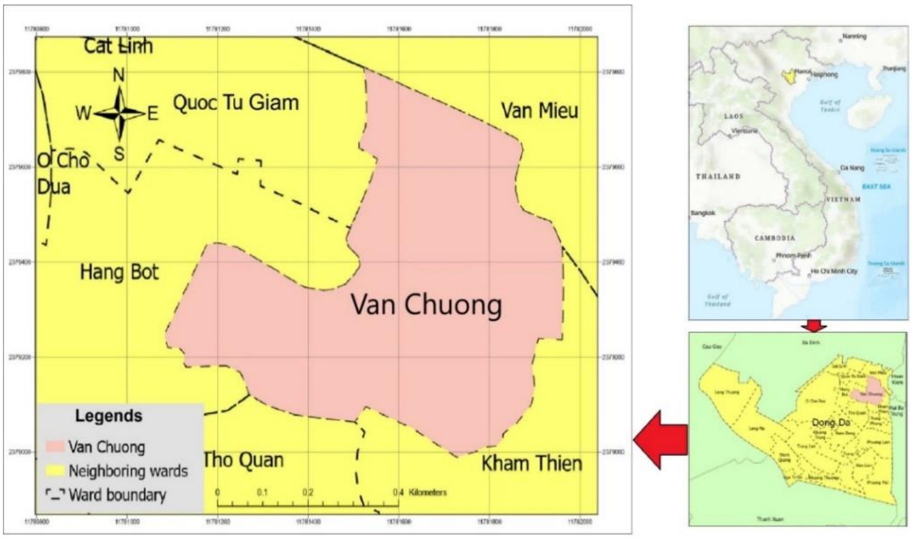

Figure 1. Administrative map of Van Chuong ward, Dong Da district, Hanoi city.

2.2. Methodology

Urban technical infrastructure databases are vital for city planning, management, and sustainability. Various methods exist, each with unique advantages and limitations [20]. GIS-based databases store, analyze, and visualize spatial and non-spatial data. They offer strong geospatial analysis, integration with urban data, and decision-making support. However, they require high-quality geospatial data, are time-consuming to develop, and need costly software and skilled personnel. Remote sensing and satellite imagery use aerial or satellite data for large-scale monitoring and change detection. While efficient and non-intrusive, this method faces resolution limitations, high costs for high-quality imagery, and requires expertise in image processing. BIM and digital twins provide detailed 3D models and real-time data integration. They enhance accuracy, monitoring, and smart city applications but are expensive, require technical expertise, and face interoperability issues. IoT and sensor networks collect real-time infrastructure data, aiding predictive maintenance and automation [21]. However, deployment is costly, requires stable networks, and raises data security concerns. Surveying and field data collection ensure high accuracy and update legacy data. Though essential, this method is labor-intensive, costly, and prone to human error. Crowdsourced and open data platforms allow public contributions for cost-effective data collection. While improving accessibility and real-time updates, they pose reliability, standardization, and verification challenges.

A hybrid approach, integrating GIS, IoT, and remote sensing, enhances database effectiveness [22]. The choice of methods depends on data availability, budget, and technology, ensuring more comprehensive and sustainable urban development. The method selected in this study is a combination approach. The national geographic database is established using imagery, field surveys, and GIS. This database is first used to extract urban technical infrastructure. Subsequently, relevant documents are collected and standardized. Finally, a new field survey is conducted to supplement the data. These three methods are integrated to construct the urban technical infrastructure in the study area, leveraging their respective advantages and practical applicability.

2.3. Process

A workflow diagram illustrating the steps involved in constructing the database can be seen in Figure 2.

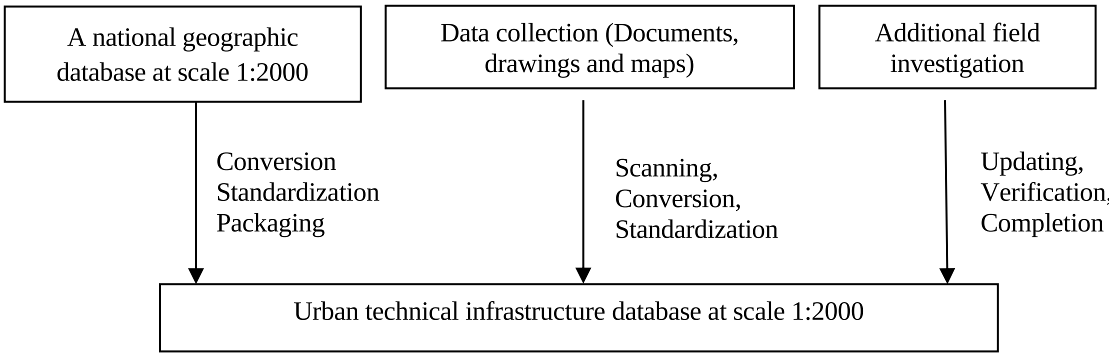

Figure 2. A workflow diagram for constructing the urban technical infrastructure database.

The structure of urban technical infrastructure database is built based on Circular 26 of the Ministry of Natural Resources and Environment [23]. First, the urban infrastructure database layers will be extracted from the national geographic database at a scale of 1:2000. Subsequently, any missing urban infrastructure database layers will be gathered from supplementary sources, including relevant records, maps, and additional fieldwork.

a) Urban technical infrastructure layers extracted from national geographic database at scale 1:2000

The national geographic database, built in 2017, was developed using specialized software (ArcGIS) to extract and manage urban technical infrastructure data. If urban technical infrastructure planning information is already available as a database or digital map, the geographic objects must be standardized according to the basic database of the Hanoi urban technical infrastructure system in terms of geometry. Four data layer groups were extracted from the national geographic database, including traffic (narrow roads, internal roads, road surface), administration (borders, etc.), hydrology (still water), and population (houses, functional areas, bare land).

This process involves converting existing content while ensuring spatial accuracy, standardizing geographic objects per the urban technical infrastructure GIS model, and packaging data in the required format with visual representations and metadata. Once properly classified and structured, the data is converted to Geodatabase format. For example, the urban road infrastructure object is extracted from the base database, and the urban infrastructure segment layer, along with related objects, is standardized according to the linear referencing event model. The absolute boundary continuity of objects is maintained based on the accuracy of the city's data, ensuring that no breaks occur along the route.

The standardization of urban technical infrastructure data enhances accuracy by systematically updating field data, validating topology, and verifying attributes. Key elements like bridges and culverts align precisely with road vertices, while management locations are regularly updated. Attributes such as length, kilometer markers, and event addresses follow operational guidelines. The 1/2000 infrastructure database ensures logical connectivity, uniform road names, and unique codes. In Hanoi, an integrated database links spatial and non-spatial data for efficient management. Standardization extends to roadways, construction corridors, intersections, and overpasses, maintaining topological integrity. Additionally, trees and lighting systems are spatially standardized through an independent object layer.

b) Urban infrastructure database layers are created from data collection

Data collection includes relevant documents and texts in both paper and digital formats (e.g., DOC, PDF), as well as drawings and digital maps (e.g., AutoCAD files). All collected materials are digitized and stored in digital form. The GIS data conversion process generally involves several key steps. First, if an AutoCAD digital version of the maps is unavailable, they need to be scanned. Next, the maps must be converted to the VN-2000 coordinate system if they are not already in this system. If an AutoCAD digital version is still unavailable, the maps are then vectorized. Following this, data layers are standardized to ensure consistency. Finally, attribute information for objects in the GIS data layers is updated to complete the conversion process.

The final output of the digitization and GIS process includes a structured folder containing digital and scanned maps/drawings, digital and scanned documents/texts, and standardized GIS data layers. These GIS data layers are stored in appropriate formats, ensuring they are ready for integration into GIS information systems. Eight data layers were analyzed from various documents, including manholes, shade trees, drainage channels, drainage sewers, light stations, detention basins, outlet gates, and drainage stations.

c) Urban infrastructure database layers created from additional field investigations

To address incomplete or missing data objects, a survey must be conducted to supplement the information. The process involves three key steps. First, existing data is edited and updated by assessing the initial data collection time, identifying areas that require updates, converting coordinate systems, transforming data formats, digitizing maps, and standardizing content. Second, field measurements and data verification are performed to check, supplement, and correct data, which includes defining boundaries, identifying measurement areas, mapping routes, and ensuring standardization. Finally, an on-site investigation is conducted to collect missing data, verify attributes, and complete the database, ensuring accuracy and completeness.

Four data layers were analyzed based on additional field investigations, including manholes, shade trees, drainage channels, drainage sewers. Additional objects are identified from urban technical infrastructure management documents or through direct field measurements. Essential attributes such as road codes and road names must be verified. If construction conditions allow, additional measurements can be combined with event verification along the route.

d) Building urban technical infrastructure database in experimental area

The experimental urban infrastructure database will be developed by integrating data from national geographic, documents, and field survey database layers. Some data layers in this database group are managed separately, while their attributes belong to other groups. For instance, in the park data layer, tree data is included. While tree data is managed under the tree database group, its attribute information remains associated with the park data layer. This structure ensures that data is properly categorized while maintaining accurate relationships between different infrastructure components.

The spatial determination of objects for standardizing the event model on the line (Event Linear Referencing) follows a structured process to ensure accuracy and consistency. First, road network integration and terrain overlay involve incorporating road name attributes from the Hanoi urban technical infrastructure database with terrain layers, such as place names and topography, to facilitate route identification both on maps and in the field. Second, mapping key locations and infrastructure elements requires using documents and reports to pinpoint key elements, including route start and end points and infrastructure such as bridges, tunnels, and culverts. Kilometers (km) are used as the standard unit of measurement, and any discrepancies between the geographic dataset and external data are adjusted accordingly.

Third, standardizing line-type objects involves systematically adjusting inconsistencies in measured distances across the entire route to maintain accuracy. Fourth, ensuring accuracy and standardization allows for precise determination of route lengths and locations, supporting future updates to the Hanoi urban infrastructure database. Finally, handling existing urban infrastructure objects ensures consistency in the dataset. Objects present but not officially listed remain unchanged, but those with street names are assigned unique street codes.

The standardized data must be edited for proper visualization in ArcGIS or other application software. This process involves three key aspects: displaying the Urban Technical Infrastructure

Network by management hierarchy to clarify the system, representing key attributes like operational status, and identifying flood points for better urban planning and infrastructure management. For symbol design in ArcMap, regulations must be followed. The topographic background should use designs from Hanoi's urban infrastructure database, while specialized content should follow thematic maps with adjusted symbol sizes. All edits must ensure clarity, ease of access, user familiarity, and a compact structure for quick display.

The list of main urban infrastructure data layers in the experimental area is presented in Table 1. These layers were studied and synthesized based on three input databases: the national geographic database, document records, and additional field investigations.

Table 1. List of urban infrastructure data layer groups in the study: (1) layers sourced from the national geographic database; (2) layers sourced from documents; (3) layers sourced from field investigations.

Database Group	Data layer
National Geographic Database	1. Traffic (1)
	2. Administration (1)
	3. Hydrology (1)
	4. Population (1)
Tree/park database	1. Shade trees (2) (3)
	2. Drainage sewers (managed in the drainage database group, with attribute information belonging to the tree/park database group) (2)
	3. Manholes (managed in the drainage database group, with attribute information belonging to the tree/park database group) (2) (3)
	4. Drainage channels (managed in the drainage database group, with attribute information belonging to the tree/park database group) (2)
Lighting database	1. Light Stations (2)
	2. Lampposts (management in the lighting database group, with attribute information in the tree/park database group) (2)
Drainage database	1. Drainage sewers/ Drainage channels/ Ditch/ River (2) (3)
	2. Outlet gates (2)
	3. Detention dasins (2)
	4. Manholes (2) (3)
	5. Drainage Stations (2)

3. Results and discussions

The urban technical infrastructure database product of the experimental area of Van Chuong ward, Dong Da district, Hanoi city, built in the study (Figure 6) will include database layer groups extracted from the national geographic database (Figure 3), database layer groups collected from related documents (records, maps, ...) (Figure 4), and database layer groups from additional field investigation (Figure 5).

The urban technical infrastructure database layer group, extracted from the national geographic database, consists of eight database layers, with houses and road surfaces being the most numerous and evenly distributed throughout the ward. Another layer group, updated from related records and documents, consists of four layers, with drainage channels and shade trees dispersed throughout the area. Notably, shade trees are concentrated in the southwest of Van Chuong Ward, as identified through document analysis. Additionally, the layer group derived from field investigations comprises eight layers, with drainage channels and manholes being the most common, primarily located in the northwest, southwest, and central parts of the ward. Overall, the comprehensive urban technical infrastructure database for the research area contains a total of 16 database layers, with houses, road surfaces, and drainage channels being the most prominent. This highlights Van Chuong Ward's dense urban infrastructure system, emphasizing the need for systematic and scientific management.

The final product is a geodatabase file (*.gdb) formatted with the VN2000 coordinate system, UTM projection grid, 49-zone, and a 105-degree meridian. To ensure the accuracy of the collected data, different types of data require specific collection methods. For location and elevation data, high-precision RTK measuring equipment will be used to achieve accurate spatial positioning. For image data, mobile devices will be used to capture clear, high-quality images of each object in the field, ensuring that the images are not blurred and accurately represent the features. For attribute information, a combination of field data collection and the latest managed information from relevant units, provided in Word or Excel format, will be used. This approach ensures that the constructed database accurately reflects the actual status of trees, parks, and other urban assets.

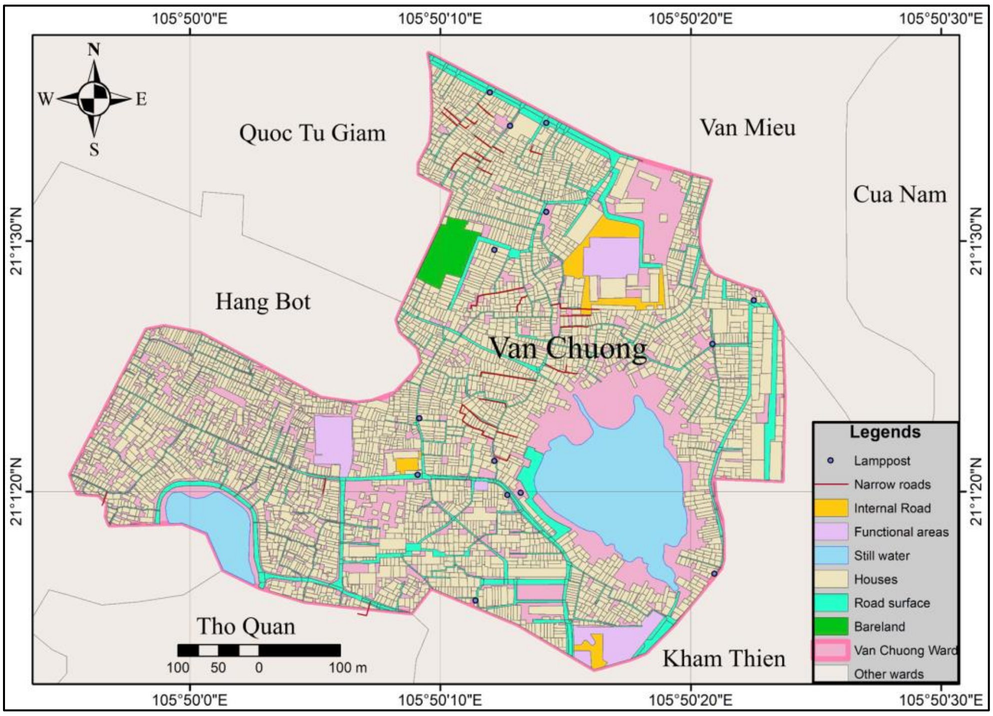

Figure 3. Urban technical infrastructure layers extracted from national geographic database at scale 1:2000.

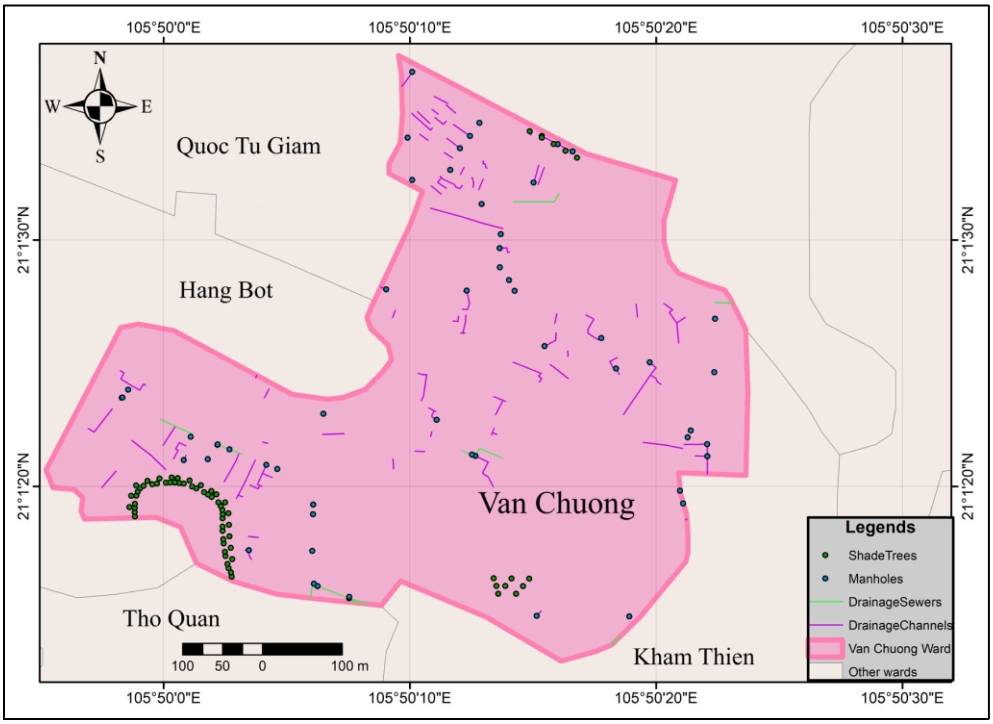

Figure 4. Urban technical infrastructure layers from additional information document profile.

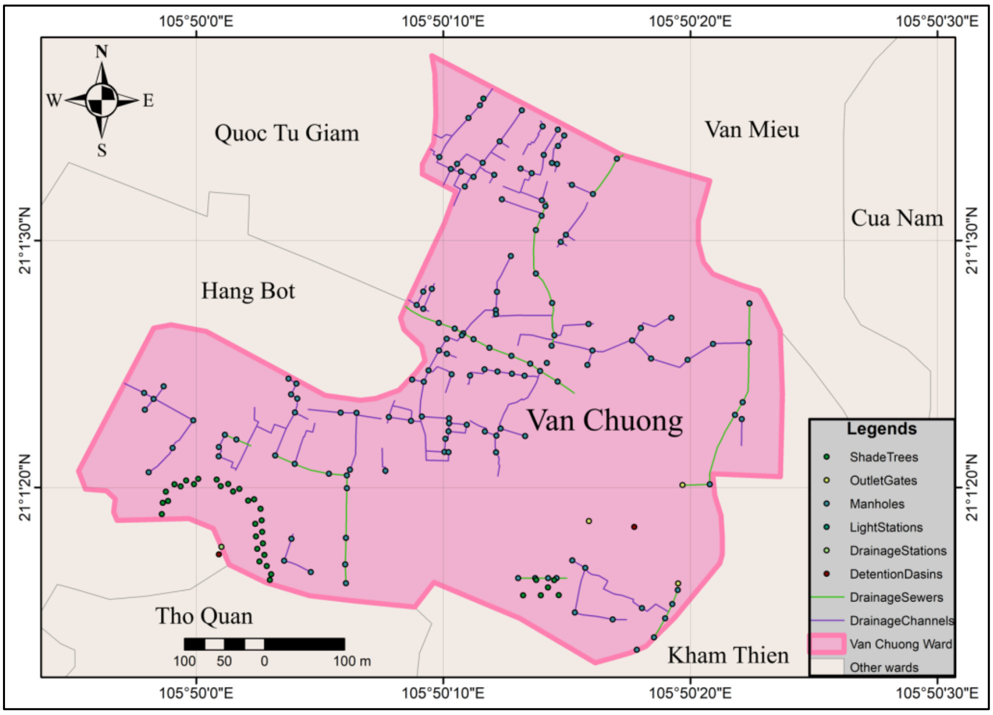

Figure 5. Urban technical infrastructure layers from the field-trip.

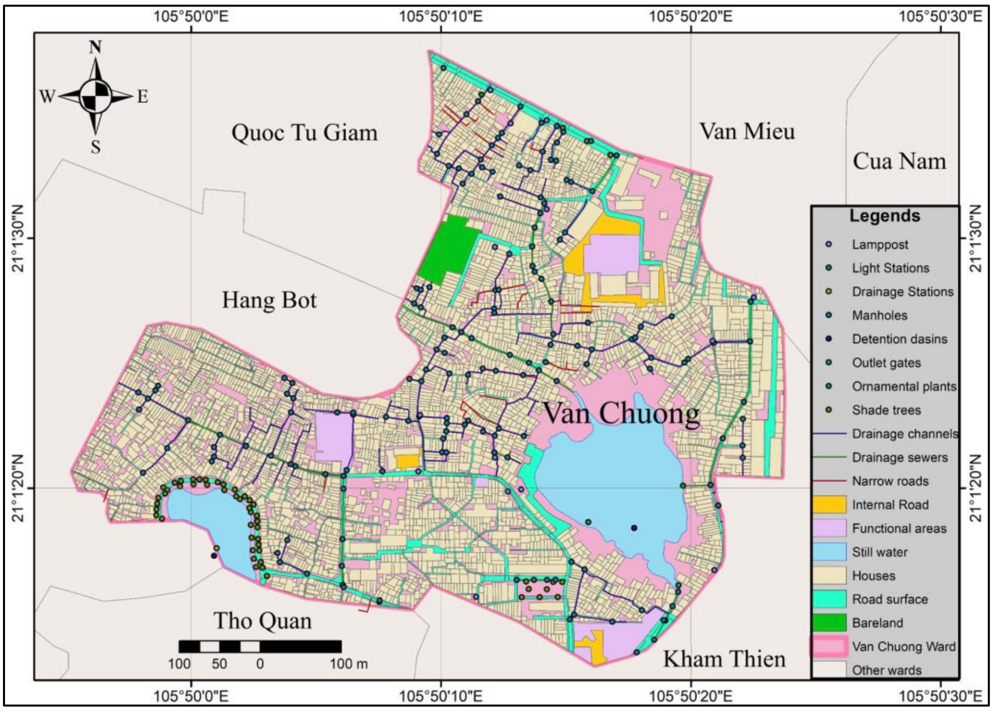

Figure 6. Urban technical infrastructure of the research area of Van Chuong ward, Dong Da district, Hanoi city.

The urban technical infrastructure database integrates standardized spatial and non-spatial data from various data sources, structured according to a predefined data model. It is stored in the Geodatabase Personal format, ensuring spatial accuracy equivalent to geographic datasets at a scale of 1: 2,000. Furthermore, the accuracy of object attributes is maintained, aligning with both the geographic base data and thematic information of the urban technical infrastructure system.

The objects in the terrain background package are derived from the original data source but have been edited to meet data presentation requirements. Specialized urban technical infrastructure elements, such as routes and associated structures, are fully detailed and correspond to the compiled list of objects from statistical reports on urban technical infrastructure at all levels. The data source is highly reliable, incorporating various input types, including the background database, specialized urban infrastructure documents, and additional field measurements. Data accuracy and consistency are ensured through assessments of value domain conformity and spatial relationships within the urban technical infrastructure system.

Database products simplify management and ensure the accuracy and consistency of urban technical infrastructure data, contributing to enhanced administrative capacity and operational efficiency. For state management agencies, these products offer several significant advantages [24]. They provide comprehensive coverage of all issues related to the technical infrastructure system managed by various units. They also enable centralized and objective monitoring of urban planning inspections and order enforcement. Additionally, they help improve the efficiency and lifespan of infrastructure by ensuring strict management of operations and maintenance. By streamlining the appraisal and inspection process, these products save time and effort in detecting violations. Furthermore, they reduce the time required to look up, synthesize, and compare data on the current state of urban infrastructure, as this information can be directly retrieved from the database.

In addition, for management levels, having comprehensive data in urban technical infrastructure management enables informed decision-making and allows for full control over the planning process, project investments, and the current status of infrastructure within the management area. For businesses, these database products offer several key benefits [25]. They facilitate the efficient collection and development of databases related to their areas of responsibility. They also provide functions that support the organization and implementation of maintenance and repair activities for urban technical infrastructure assets. Furthermore, they generate reports and synthesize data on the current status of urban infrastructure, enabling quick and accurate access to information. Ultimately, these capabilities enhance the capacity and effectiveness of urban technical infrastructure asset management.

Thus, the development of urban technical infrastructure databases offers numerous advantages, including improved management and planning efficiency, optimized resource utilization, faster decision-making, enhanced transparency and data-sharing capabilities, and the integration of modern technology. However, challenges persist, such as high investment costs for hardware, software, and human resources, strict technical requirements, data security concerns, difficulties in data synchronization and updates, and dependence on technology. Despite these challenges, with technological advancements and effective collaboration among stakeholders, the construction of urban technical infrastructure databases remains an inevitable trend toward smart cities and sustainable development. To ensure successful implementation, it is vital to maintain close coordination among management agencies, experts, and the community while continuously updating data to reflect urban development needs.

4. Conclusion

In conclusion, the study has created a comprehensive urban technical infrastructure database consisting of fifteen data layers and detailed database groups, incorporating data extracted from the geographic database, analyzed from relevant records and documents, and supplemented through additional fieldwork. The construction of this urban technical infrastructure database plays a vital role in the management and sustainable development of modern urban areas. The research findings emphasize that the use of a digital database system improves the accuracy of urban planning, minimizes management errors, and supports more efficient decision-making. This study will be valuable for local managers in the effective management and planning of urban technical infrastructure within the research area.

Developing an urban technical infrastructure database is not only an urgent requirement in the context of rapid urbanization but also a fundamental step toward establishing a smart and sustainable urban management model. Future research will focus on developing tools for managing groups of technical infrastructure databases within the study area, aiming to enhance management efficiency. Moreover, the research methods and processes presented can be applied to other regions, contributing to the standardized and integrated management of urban infrastructure at the ward, district, and city levels.

Enhancing the efficiency of urban technical infrastructure data collection, storage, and management in Hanoi requires an integrated approach involving technology, management, and policy. Data collection should be standardized and modernized using GIS, BIM, LiDAR, IoT, and multi-source integration. A centralized storage system leveraging cloud computing and blockchain must be developed with robust security measures. Additionally, a smart management system incorporating AI, Big Data, and SCADA should be synchronized with urban platforms. Policy support and inter-sectoral collaboration, including regulatory frameworks, cooperation, and workforce training, are essential. Pilot implementations in central districts and integration with smart urban projects will facilitate city-wide deployment.

Author contribution statement: Designed and conducted the research; analyzed and interpreted the data; wrote and edited the draft manuscript: H.H.T.

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