Using GIS to Manage Clean Water Supply System: A Case Study of Hoan Kiem District, Hanoi, Vietnam

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Abstract

Managing clean water supply systems is the goal of many countries in the world, especially large cities in developing countries including Vietnam. In Vietnam, urban areas are facing many challenges in management such as building data sets and applying technology in management. Using smart management tools with large data sets will limit water loss, improve management efficiency, save costs and time. In Hanoi, there is still no synchronization of data and technology in managing clean water supply systems. The article shows the process of building a water supply system database, steps to normalize data on a mathematical basis and standardize spatial and attribute data. To introduce the process of building a GIS database on ArcGIS software to manage clean water in Hoan Kiem District, Ha Noi, Viet Nam. This is also a typical pilot for application in many other locations in different cities in Vietnam and can be connected to create big data in water supply management in many different cities in Vietnam.

1. Introduction

Clean water is a basic human need, which is not pure water (like distilled water) but will include dissolved compounds that are not harmful to health[1, 2]. Many parts of the world today are facing a lack of clean water, especially developing countries. According to Unicef, water shortages have occurred on a large scale, affecting many people around the world and it is estimated that by 2025 the number of people affected by water shortages in the world will reach 1,800 million people. In Vietnam, there are many areas where clean water is lacking, and polluted water sources must be used in daily activities, not only in rural mountainous areas but also in urban areas.

The clean water supply system in Ha Noi, the capital of Vietnam, provides 29 districts and 01 town mainly using clean water from 15 underground water plants, 3 surface water plants and 14 local water supply stations The rate of people in Hanoi who have access to clean water system is close to 100%, but there are still many places where there is a shortage of local domestic water with the rate of water loss in 2013 and 2015 was 27.5% and 22%, respectively and over 18% by 2020. According to Decision No. 2147/QD-TTg dated 24th November 2010, the Prime Minister approved the national program to combat water loss by 2025 the average rate of loss and loss of clean water will be 15% in Viet Nam[3]. The main two reasons for the loss of clean water are:

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Firstly is the lack of awareness of water use which leads to waste, lack of sense of saving, and the amount of water used is much larger than the amount to be paid, many construction units break or break water pipes but were not declare, loss of clean water are due to residents arbitrarily connecting to the water supply, taking water from the city pipeline, using clean water for car wash business, production services, etc., without registration, business, or improper use, etc... and the second is there are still many areas in Hanoi using old, degraded, cracked water pipes that leak water into the ground leading to the loss of clean water. Secondly, there is no database of clean water supply systems as well as the application of smart management technology. Therefore, the management of the system or making management decisions and solutions are not highly effective

Modern computer software and technology is used in almost all areas of human activity[4]. GIS technology has been applied in many fields including infrastructure, urban services, GIS applications are increasingly upgraded and strongly developed. A geographical information system (GIS) for collecting, editing, integrating data, can query spatial data and attributes, model data, and build spatial maps[5].

Geographic information systems (GIS) are useful tools for processing spatial data of urban objects, the function and tools of GIS software support managers making decisions[6]. Nowadays, with the development of information technology, GIS has successfully solved many problems related to urban management[7]. Compared with other technologies, GIS is highly appreciated in data management including spatial data and attributes of objects.

GIS has solved many management problems related to water environment, clean water management for an area. It provides tools in database building such as input data entry, map digitization, standardize and convert data formats, assign coordinate systems and projection, query spatial of objects in the water supply system, solve problems such as finding locations, calculating distances between objects.....

GIS application is highly effective through the use of GIS technology in many fields in urban management, infrastructure management, clean water supply systems... especially in process spatial analysis problems. [8]. It can be seen that GIS is a technology with powerful functions in spatial analysis, creating reports such as maps, charts, and modeling urban objects, effectively supporting managers. The application of GIS in clean water system management will bring high efficiency [9].

In addition, GIS has the function of connecting spatial data and attribute data in big data, data layers are established to support management agencies, communities, data builders to access and use together. Information in the GIS database can be used online to support providing users with necessary information quickly.

Using GIS technology to manage an urban clean water system will bring benefits to residents. When residents encounter service problems, system managers can immediately provide necessary information or people can access and find out the current status of their services. GIS technology is the most effective tool for management and maintenance of clean water systems in urban areas [10]. Applications of GIS technology in clean water system monitoring and management has been long recognized in many countries. Building a GIS database for management in the period of development into a smart city is a very necessary task in Ha Noi.

In Vietnam, even in large cities like Hanoi, GIS application in clean water system management is still fragmented, unsystematic and inconsistent between provinces and districts. Data connection in the same mathematical system has not been implemented. Technical criteria for designing database structures are not available and there are no legal documents on this issue, so there is no city-wide shared dataset.

The Environmental Systems Research Institute (ESRI) is the world's largest GIS software developer, with software developed by the company accounting for 40.7% of the market. Many countries around the world have used ESRI's GIS software, and in Vietnam, authorities at all levels have issued documents requiring the use of this company's software to build GIS databases in planning and management [11, 12].

ArcMap is the most commonly used software in many fields including water supply system management, the technical and management solutions of this software are always upgraded. The software supports editing and updating data, querying technical and customer information quickly, and can store large information sets[13]. In addition, this software is very strong in spatial analysis, so the government also issued a request for agencies to use ArcMap software to create large urban data sets and can connect with other data quickly and conveniently.[12, 14].

The purpose of the article is to apply GIS technology in building a database of water supply systems with a case study in Hoan Kiem district, Ha Noi, Vietnam. A technical framework for the database with the groups of objects belonging to the water supply system is formed, including the requirements for the coordinate system and the technical requirements for spatial data and attribute data. The results of the study contribute to and connect with other districts of Ha Noi in the city's metadata collection. Besides, this result is a reference for districts across the country, especially for Hoan Kiem district, which is important information to help manage and connect data with other districts of Hanoi.

2. Study Area

Hanoi is the capital of Vietnam, located at 20°53' to 21°23' North latitude and 105°44' to 106°02' East longitude. After expanding the administrative boundaries in 2008, Hanoi now has 17 rural districts, 12 districts, 1 town.

According to statistics from the Hanoi Population Department, in 2023, the population of Hanoi reached nearly 8.5 million people, ranking second in the country, accounting for about 8.5% of Vietnam's total population.

Hoan Kiem is a central (core) district of Ha Noi city, the population of Hoan Kiem is around 212,921 people, with a population density of 39,873 people. Hoan Kiem has 42.000 households and 17 thousand businesses in the area. Currently, Hoan Kiem has 18 wards directly under the structure of the city (figure 1). Clean water supply system of all districts of Hanoi city has not been managed on the GIS system. To improve efficiency and meet the connection requirements of all levels of government, it is necessary to establish a GIS database for each district to connect the GIS database of the districts into big data in the roadmap to develop Hanoi into a smart city.
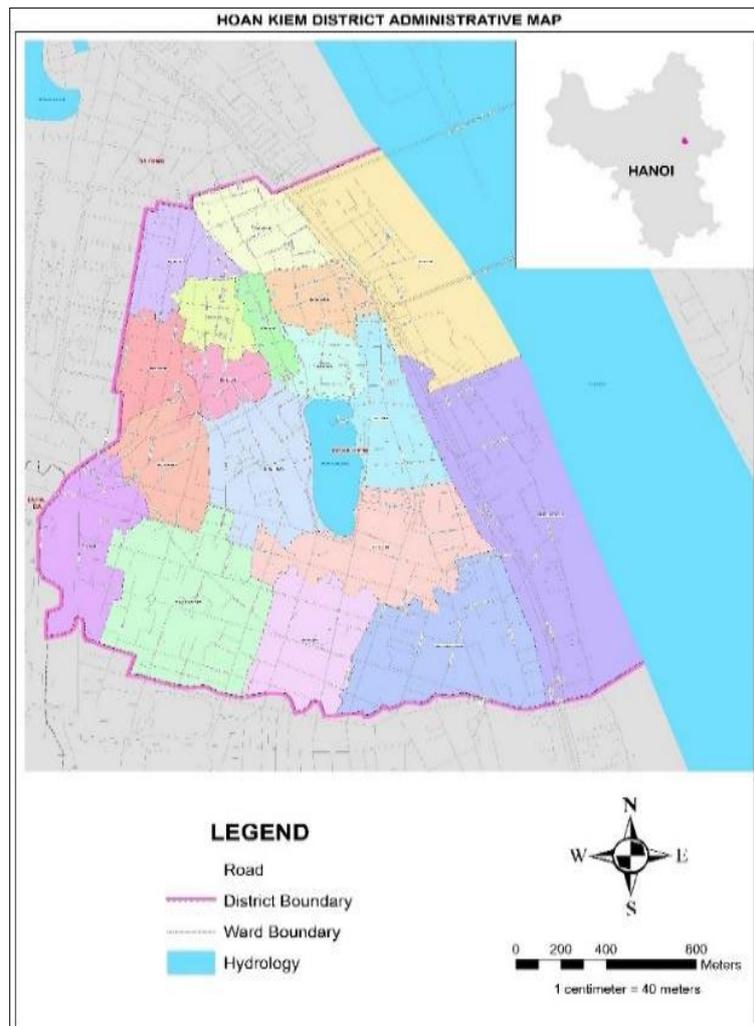

Fig. 1 *Study area (Hoan Kiem district in the core of Ha Noi city)*

3. Methodology and Data Collection

3.1. Methodology

The figure 2 presents the workflow for establishing the clean water supply system database (GIS). To reach the results, this process was carried out through stages:

Collecting data (map of water supply network, water meter points, household owners, attributes of objects in the clean water supply system)

Data frame structure design (ensure easy connection with other data)

Convert data to GIS environment (convert from data in other formats to .shp)

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Normalizing spatial and attribute data (aims to transform the values of the dataset into the same scale)
Building GIS database of clean water supply system in Hoan Kiem district
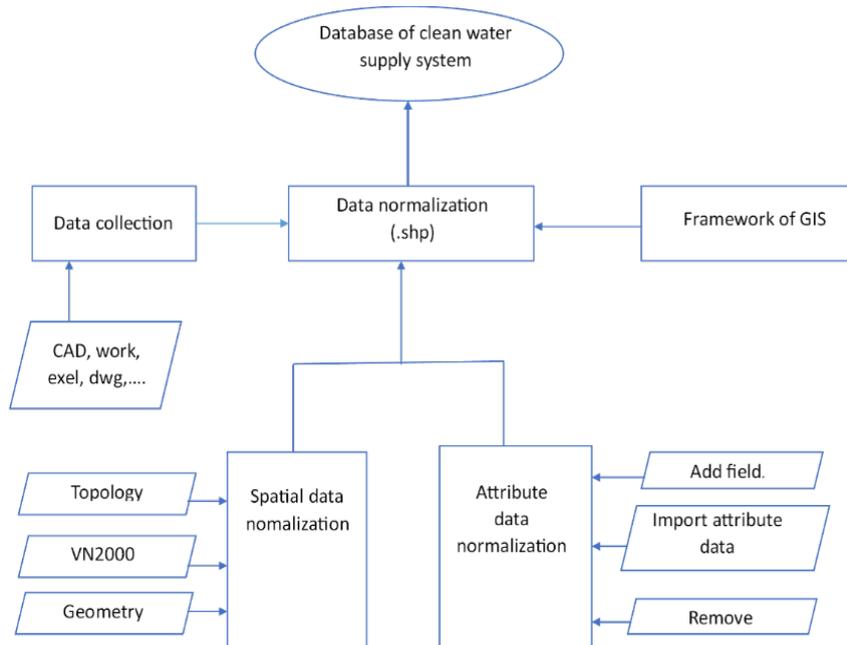Finally, the results were discussed.

Fig. 2 *The workflow for building the clean water supply system database (GIS)*

3.2. Spatial Data Collection

The data collection process is conducted after the survey phase, the data includes clean water supply system drawings in CAD, word, excel format...; hard copy such as property photos, as-built drawings, description documents... and some data collected from other sources such as satellite images...

ArcMap software can convert many types of collected data in different formats to GIS, not only digitizing maps but also digital data from other technologies can be recognized and brought into the GIS environment [15]. Two types of data models in GIS are spatial data and attribute data, the structure of GIS database for clean water supply system management also including spatial data and attribute data. Spatial data types such as points, lines, and polygons that describe shape and location of objects in a clean water supply system, these spatial features contain the richest information.

In this paper spatial data sources come from many different formats (.dwg, .dng, .jpec...) (Figure 3) such as maps of land use, topography, drainage, solid waste, lighting... all of them are converted to shapefile format (.shp). Spatial data in the research were collected in groups (Figure 3)[16, 17]: elements such as water source, water intake point, raw water works, raw water pumping station, raw water valve, raw water pipeline...were collected;

The coordinates of objects in clean water supply system data was collected by using GPS technology and data from drawings in .dwg format converted to (Figure 3): water metering total, customer water metering, clean water pipeline, clean water valve, plant and water supply station, connection point, point of maintenance and repair, point of breakdown, loss water point.
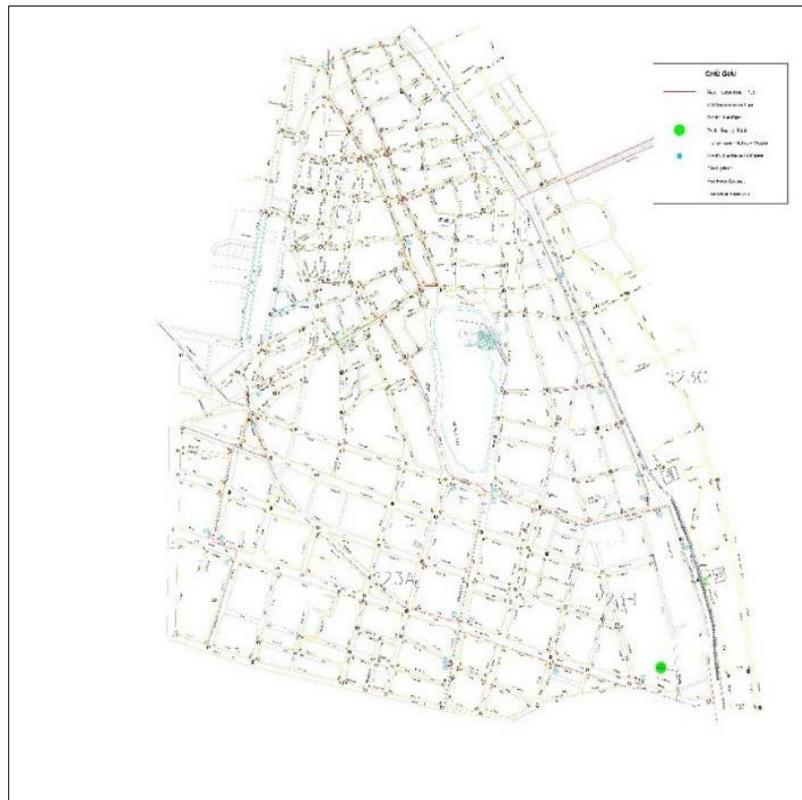
Fig. 3 *Clean water supply network of Hoan Kiem district (.dwg)*

3.3. Attribute Data Collection

Attribute data stored in GIS is arranged in rows and columns, each row represents a spatial object, in the data set the number of rows corresponds to the number of objects, and a spatial object has as many properties as columns (attribute fields).

Attribute data is often presented in hard copy, word, excel, even on links or images. Attribute data objects of clean water supply system in this research of will be collected and divided into 07 main groups including (figure.4)[18]: 1)Data group on property management in which spatial objects will be assigned object codes and object names; 2) Data group on property location: house number, street name, commune name, ward name, district name, water supply area name, coordinates... 3) Data group on property specifications: diameter, length, material, flow, pressure, 4) Asset life data group: year of installation, year of manufacture, shelf life...5) Data group of asset origin: country of manufacture, brand production unit, design unit, construction unit, supervisory unit, management unit...6) Group of incident data, asset repair: number of incidents, number of repairs, number of replacements , replacement time, repair time, cost...7) Data group on updating assets: updater, update date...

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FID	Shape *	Mã đối tượng	Mã vùng cấp nước	Mã khu vực cấp nước	Đường kính trong	Đường kính ngoài	Chiều dài (m)	Chất liệu	Năm lắp đặt	Độ nhá
0	Polyline	TD001	9	KV1	210	220	50	HDPE	2010	
1	Polyline	TD002	9	KV2	210	220	100	HDPE	2010	
2	Polyline	TD003	9	KV3	210	220	150	HDPE	2010	
3	Polyline	TD004	9	KV4	210	220	200	HDPE	2010	
4	Polyline	TD005	9	KV5	210	220	150	HDPE	2010	
5	Polyline	TD006	9	KV6	210	220	150	HDPE	2010	
6	Polyline	TD007	9	KV7	210	220	120	HDPE	2010	
7	Polyline	TD008	9	KV8	210	220	140	HDPE	2010	
8	Polyline	TD009	9	KV9	210	220	210	HDPE	2010	
9	Polyline	TD010	9	KV10	210	220	250	HDPE	2010	
10	Polyline	TD011	9	KV11	210	220	60	HDPE	2010	
11	Polyline	TD012	9	KV12	210	220	80	HDPE	2010	
12	Polyline	TD013	9	KV13	210	220	110	HDPE	2010	
13	Polyline	TD014	9	KV14	210	220	220	HDPE	2010	
14	Polyline	TD015	9	KV15	210	220	140	HDPE	2010	
15	Polyline	TD016	9	KV16	210	220	260	HDPE	2010	
16	Polyline	TD017	9	KV17	210	220	300	HDPE	2010	
17	Polyline	TD018	9	KV18	210	220	50	HDPE	2010	

Fig. 4 *Attribute data of objects of clean water supply of Hoan Kiem district*

3.4. Spatial Data Normalization

Normalization is a data preprocessing step, it requires accuracy to serve data classification. Besides, data preprocessing plays an important role because the data after preprocessing is the background data for the next detailed analysis [19].

Normalization is the work of organizing data according to the design structure, eliminating errors, cleaning data, filtering redundant data to improve data accuracy, supporting managers and users.

For normalizing spatial data, it is necessary to standardize according to the following requirements:

Standardize the coordinate system all spatial data of clean water supply system must be in the same local reference system(figure 5), coordinate system VN 2000 with the parameters: Ellipsoid WSG-84; Major axis (a): 6,378,137 m; The flat parameter (f): 1 / 298,257, using UTM projection (6°), length distortion k0 = 0.9996 for the principal meridian [20].
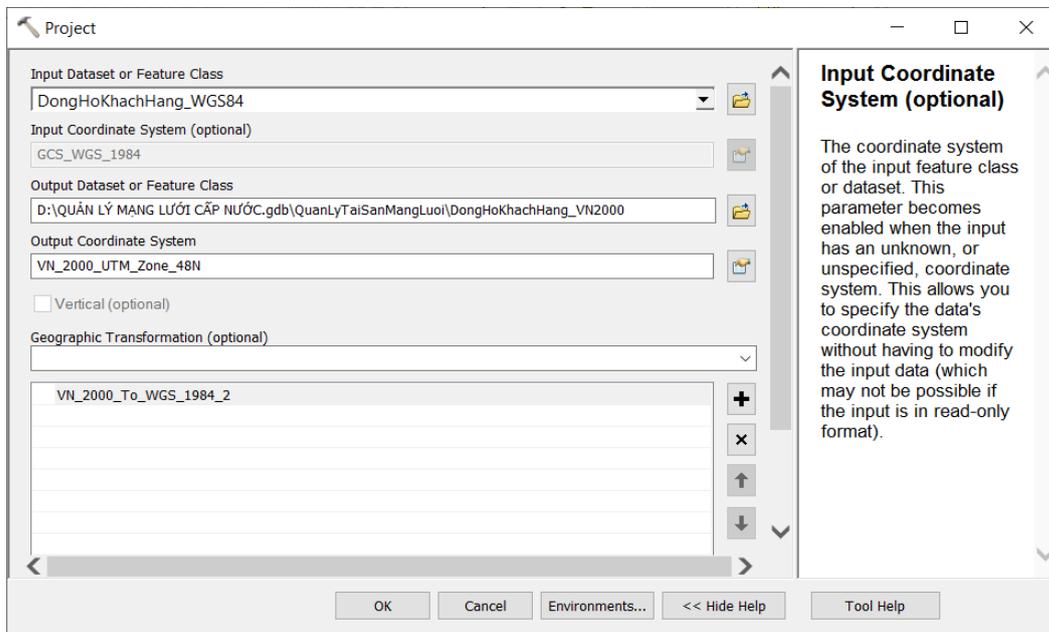

Fig. 5 *VN 2000 coordinate system*

The conversion of other data to the GIS database occurs topology errors which cause inconsistencies or violations of the spatial rules and relationships that define how features should connect, intersect, or overlap in a geographic information system (GIS). In this research, common errors such as: overlapping, duplicate (two transmission pipelines are overlap ...), distribution pipelines are not connected (figure 6)
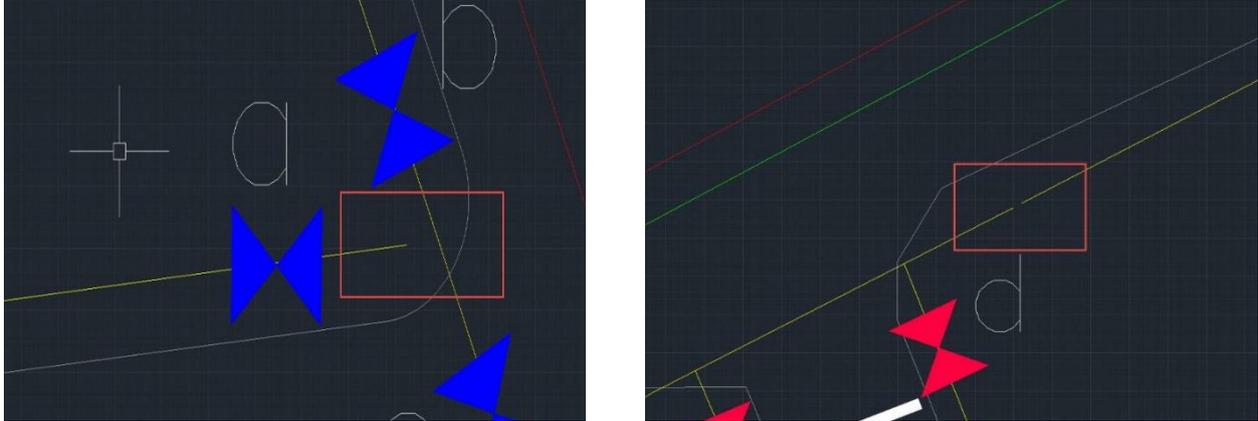

Fig. 6 *Topology errors*

Normalize geometry to check and remove objects with geometry errors, check finds features that contain invalid geometry. There were many geometric errors in the process of constructing the spatial data of the clean water supply system of Hoan Kiem district, which required the development of an error correction algorithm to replace the manual correction process. The spatial objects in this dataset were filled with attribute information during the normalization process (figure 7)

Fig. 7 *Normalize spatial data of clean water supply system (a part of Hoan Kiem, Viet Nam)*

3.5. Attribute Data Normalization

Attribute data normalization is an important step because that is the connection attribute data (data that identify, position, time and describe a spatial object) and spatial data.

ArcGIS software can store a value for a feature attribute as one of seven data types—short integer, long integer, float, double, text, date, and binary large object (BLOB).

We need to create the required attribute fields (follow the data frame structure design), then input the necessary attribute information (according to the as-built drawings, to the survey data from the field...)

The GIS database has been designed in ArcGIS 10.8, the input data including parameters of diameter, material, length, year of installation, customer information, data flow and water pressure from the data are also updated to the system.

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4. Result and Discussion

GIS database includes spatial and attribute data of objects in the clean water supply system, providing timely and accurate information for policy makers and decision makers. This software supports urban managers in providing information to stakeholders and enables community participation in building a GIS database of clean water supply systems.

The database of the clean water supply system of Hoan Kiem district has been built with spatial and attribute data in the GIS environment with the mathematical basis of VN 2000 coordinate system and scale 1:2000 (figure 8). The dataset has been deleted of errors and standardized, synchronized, easy to access and has the ability to link with other GIS databases. The structure of the Hoan Kiem district clean water supply system database is a suitable structural model for other districts of Hanoi city to use.

The GIS database of clean water supply systems also provides managers with maps, reports, charts, etc. for writing reports or presenting management plans.
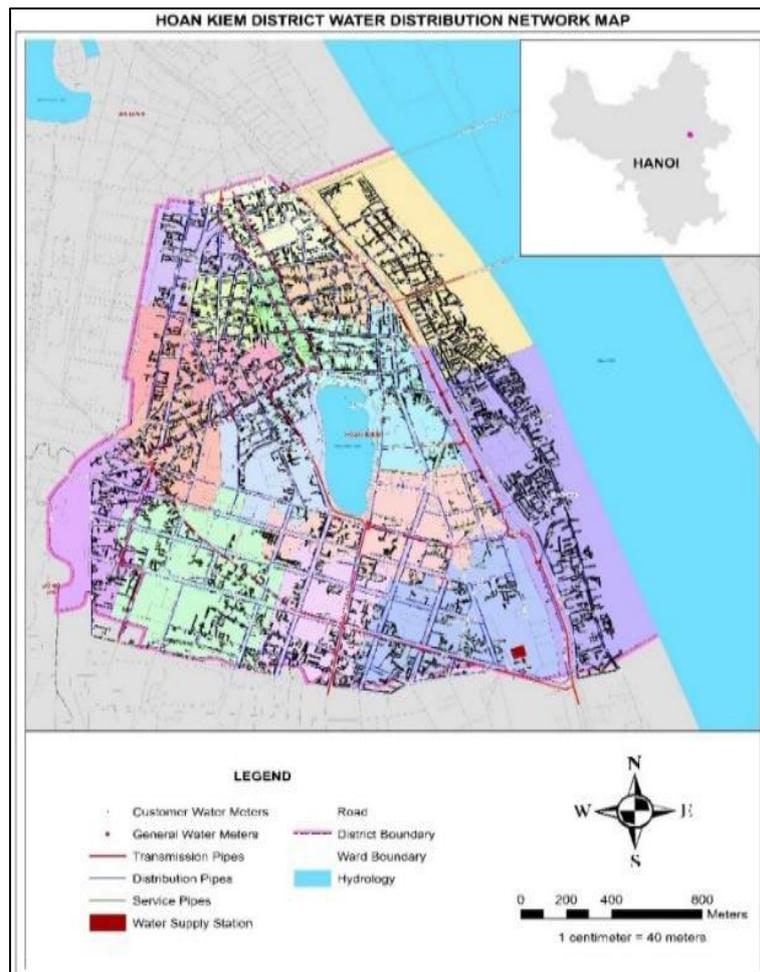

Fig. 8 *Map of clean water supply system of Hoan Kiem district*

The database of clean water supply system in Hoan Kiem district is designed to display and classification: pipelines include raw water pipes, transmission pipes, distribution pipes, service pipes, customer pipes, distribution of customers according to water usage volume, customer codes for customer meters, diameter and material for the pipeline, flow and pressure for the total meter, this information will support maps and tables for the reporting of managers (figure 9). The conversion to the prescribed format in the GIS environment is still very difficult, because the documents were previously stored in different formats (.dwg, paper version). Enhance community participation in building shared data.
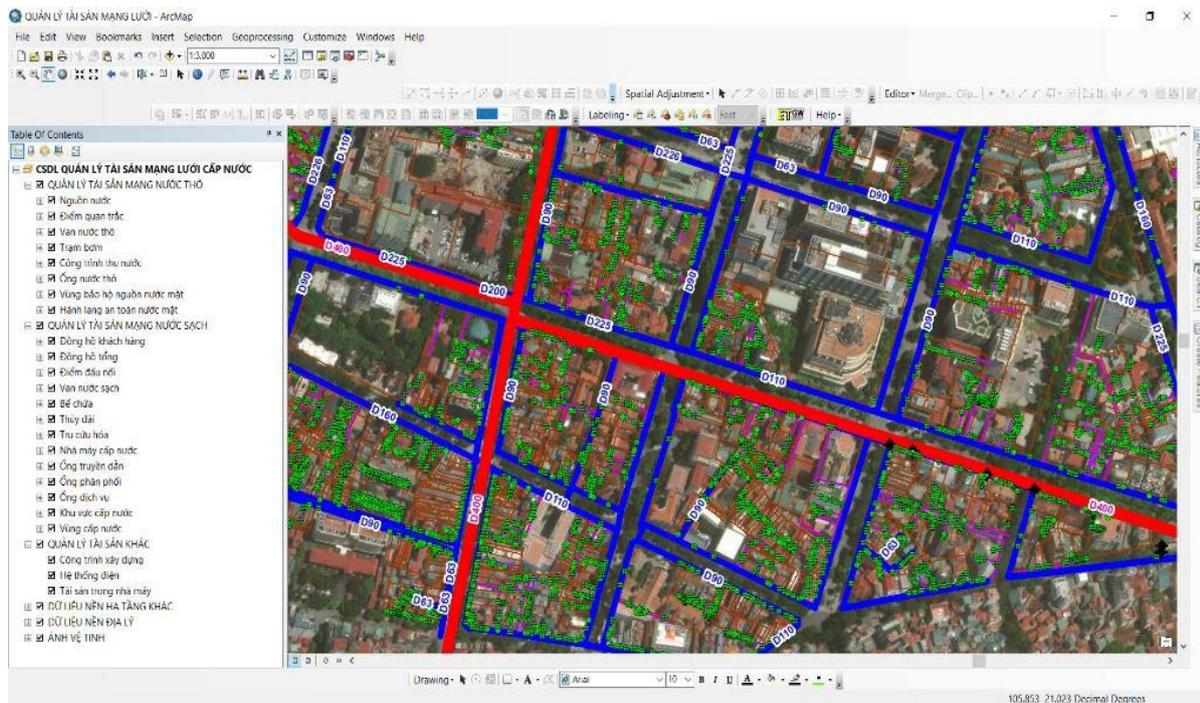
Fig. 9 *GIS database of Hoan Kiem clean water supply system*

5. Conclusion

GIS is a useful decision support tool in the management, especially the management of the clean water supply system. The establishment of a GIS database to manage urban issues is very necessary, especially in cities that have developed strongly and have not yet applied smart management technologies. Because the water supply system is stored in many different file formats, the conversion to .shp format will support the management and integration of many data types. ArcGIS is a modern spatial system that provides the best solutions to management. The GIS database was created to reduce the loss of clean water for the city, save money for clean water supply companies, and contribute to sustainable urban development.

Hanoi aims to develop into a smart city by 2030. Building a database of fields is important work in building and managing water supply system data of Hanoi to achieve that goal. To connect the data of the fields of the districts together, it is necessary to have a common process and set of technical criteria. Therefore, these results can be a model for Hanoi city to refer to and apply. It is necessary to develop a common process for building a water supply system GIS database, especially the standard systems of the database need to be unified for the whole city. Through the effective operation of this dataset, managers and authorities at all levels can refer to issue documents about the GIS data structure framework for the clean water supply system for Hanoi city.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: study conception and design: Le Thi Minh Phuong; **data collection:** Le Thi Minh Huyen, Vu Le Anh; analysis and interpretation of results: Le Thi Minh Phuong; **draft manuscript preparation:** Le Thi Minh Phuong, Vu Le Anh, Le Thi Minh Huyen. All authors reviewed the results and approved the final version of the manuscript.*

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