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ORIGINAL ARTICLES

New approach implementing GIS techniques in analyzing the production and distribution of potable water at 10th of Ramadan City

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ABSTRACT

It is worth to highlight that 10th of Ramadan City has been created to attract foreign capital, job creation opportunities for youth and to attract population increase outside Cairo. The current water service is not sufficient to achieve the objectives of the establishment of an industrial city (Castle of the Egyptian industry). The city is located at the end of Ismailia Canal which makes drinking water service is very expensive. In the same time, the Greater Cairo Water Company (GCWC) wish to provide excellent service at the lowest cost with the greatest gains while the price per cubic meter of water specified by the Egyptian government may not be increased by the Greater Cairo Water Company. The main purpose of the present study is the potentially for clarifying the power of GIS techniques in analyzing production and distribution of potable water and putting a methodology of providing excellent water service at the lowest cost and the greatest benefits for the water company during the current conditions. This will include the visualization power of GIS to classify types of distribution networks. Topology is used to verify more accurately model geometric relationships, while geometric network is used to represent and model the behavior of a common network infrastructure in the real world. Utility Network Analyst is used to set and display the network flow direction, set up and perform trace operations on the current network. The study revealed a high ability of geospatial database for managing water networks through discovering disadvantages like dead ends, as well as determining network type, network path, and verifying and repairing the connection errors. The study revealed also that most of the network pipes need to be replaced by safe new ones.

Key words: GIS; water distribution system; 10th of Ramadan City

Introduction

The Tenth of Ramadan city is located in the southern part of Sharkia Governorate and north eastern part of Nile Delta, Egypt. It covers an area of about 398 Km^2 and bordered by latitudes 30° 10' and 30° 25' N and longitudes 31° 36' and 31° 53' E (Fig. 1). The residential area is about 273 km^2. The population of the city is about 450,000 and it is planned to be 800,000 in the next few years. The whole study area has two water purification plants of capacity 570,000 m^3/day.

The city has been build up to attract employers from different Egyptian localities. Also provides job opportunities for youth and attracts peoples far from Cairo. The 10th of Ramadan city is being the castle of the Egyptian industry. The current service is not sufficient to achieve the objectives of the establishment of the city. The location of the city at the end of Ismailia canal makes drinking water service is very expensive. In the same time water company wish to provide excellent service at the lowest cost with the greatest gains, while the price per cubic meter of water specified by the Egyptian government may not be increased by the water company.

GIS has been regarded and proven as an efficient and powerful tool in the water distribution industry. According to American Water Works Association, 90% of water agencies are now partially using GIS to assist their daily operation. The business operations in the water/wastewater industry requires the district to keep complete and detailed inventory, including location and condition of all assets such as water mains, valves, hydrants, meters, storage facilities, sewer mains, and manholes. GIS is a state-of -the-art technology capable of efficiently performing all these data- related processes (Gerlech, 1963; Clark, *et al*., 1971; Aronoff, 1989; Ramirez, 1997; Nobel, 1998; Bahadur *et al*., 2000; Costelloe, 2001; De Schaetzen and Boulos, 2001; Mathiyalagan, *et al*., 2004; Nielsen, 2005; Bonniface and Coppins, 2007 and Rangzan and Mehrabi, 2007).

Production and distribution of potable water is a classical and critical problem. It is one of the most important discrete optimization problems because it serves as a model for real world problems. Real world problems that can be modelled as distribution problem category which is commonly appear in some of the utilities problems such as roads, electricity, sanitation networking and potable water production and distribution.

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The main purpose of the present study is the potentially for applying GIS techniques in analyzing production, distribution and quality of potable water and putting a methodology of providing excellent water service at the lowest cost and the greatest benefits for the water company during the current conditions.

2. Methodology:

The visualization power of GIS is used to classify the different types of distribution networks. Also, three tools of GIS have been used. The first tool is the topology tool which is a collection of rules and relationships that, coupled with a set of editing tools and techniques, enables the geodatabase to more accurately model geometric relationships found in the world. The second tool is the geometric network tool which is a set of connected edges and junctions, along with connectivity rules that are used to represent and model the behavior of a common network infrastructure in the real world. The last tool is the utility network analyst toolbar which set and display the network flow direction and set up and perform trace operations on the current network.

Thirty seven samples of potable water were collected from six districts which are completely constructed and populated. Four parameters, including residual chlorine, turbidity, conductivity, and TDS were measured for each sample to detect the quality of network water.

3. Conceptual model:

3.1. Preparing conceptual model:

The real world resources are defined from the viewpoint of data, application, extension of systems for assembling and defining required layers and there attributes. The Preparation of conceptual model “Entity Relationship Diagram” (ERD) requires five entities for water network. These entities are pipe, hydrant, pump, reservoir and valve (Fig. 2). In ERD model, spatial relationship and scale of its cardinality are presented among entities. It also helps to establish connectivity rules among network components and establishing geometric network.

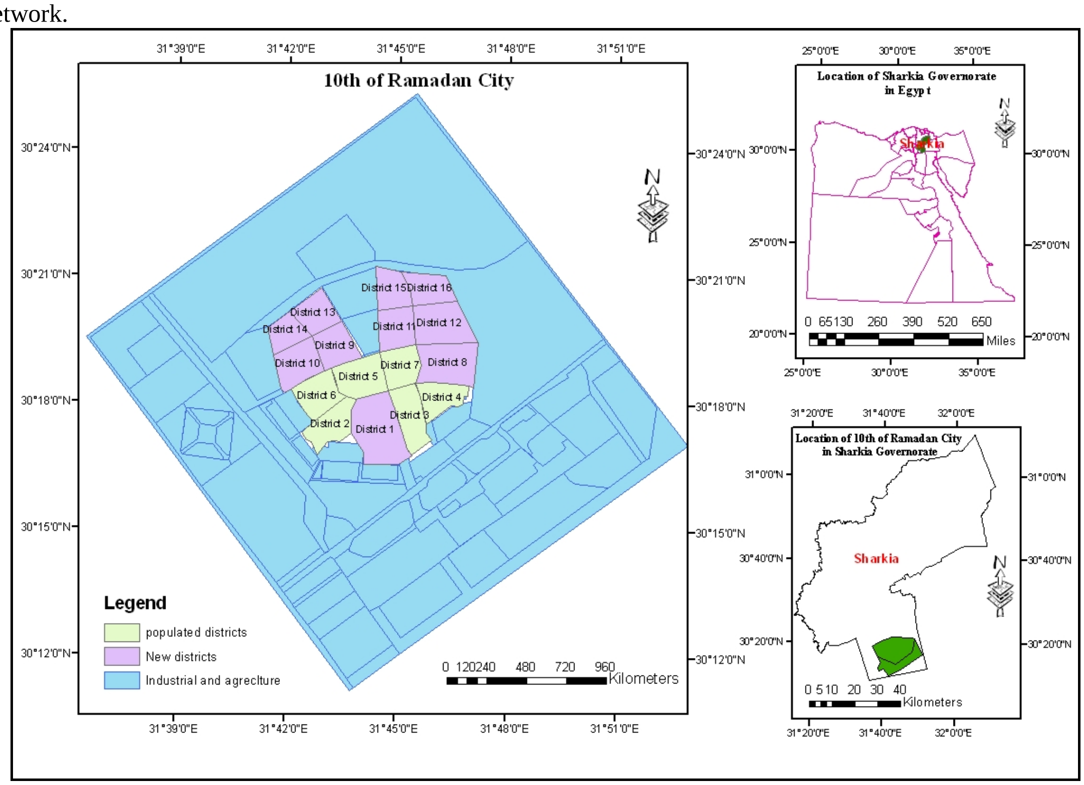

Fig. 1: Location map of study area.

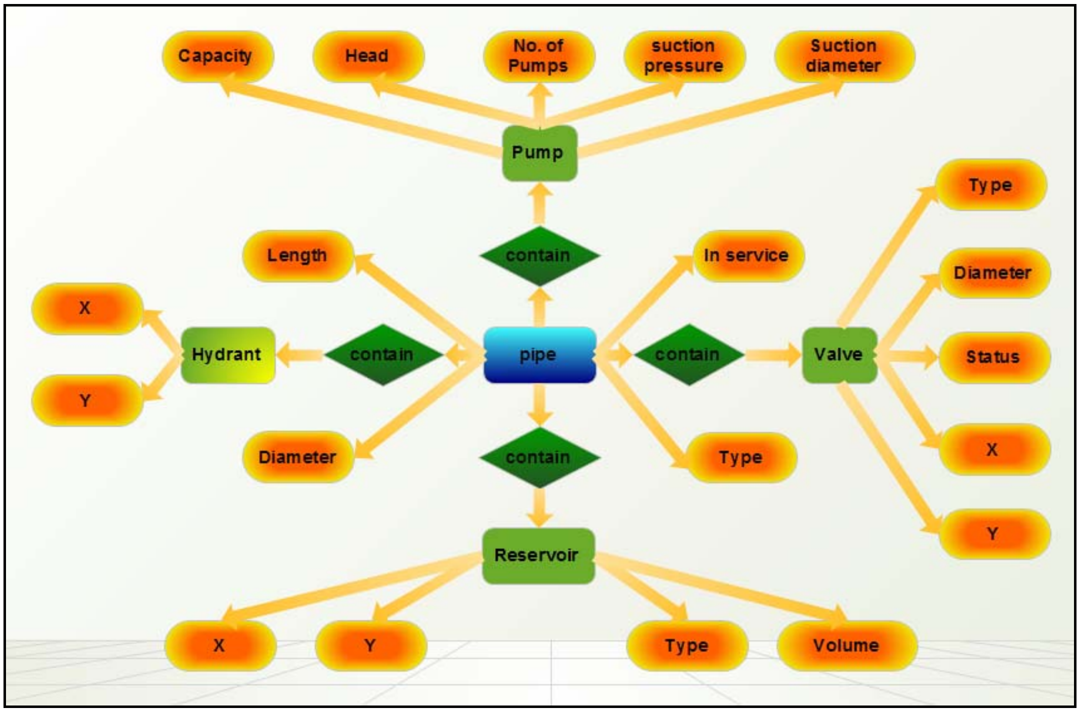

Fig. 2: Entity relationship diagram.

3.2. Geospatial database design:

Establishment of relational database has sum deficient. Nature of geospatial data doesn't appropriateness within a list structures and Structural Query Language (SQL), which is unable for geospatial concepts (Worboys *et al*., 1991). Even though some researchers have offered ways for improvement of this kind of databases. Seaborn (1995) believe that object oriented database like geospatial database will abandon relational databases. On the base of this subject, for analyzing production and distribution of potable water in 10^{th} of Ramadan city, a geospatial database is established called "Asher". According to organization needs, existing situations and future foresights (Booth *et al*., 2002), attribute domains are assigned to prevent entering attributes out of limitation.

This domain for water pipes diameter is used to referring water pipe diameter. Then three feature datasets are made according to available data including: water dataset for water network management, city dataset for keeping and managing customer' data and other civil features, and general location dataset for keeping and managing data related to general location. Then feature classes are made in each dataset by importing digital data and tables (Table, 1). Then all feature datasets are applied the same coordinate system (WGS_1984_UTM_Zone_36N) for keeping connection of topology among data.

Relationship classes are established for modeling the connection of feature classes inside geospatial database (Zeiler, 1999). Also pipe-valve relates and pipe-hydrant relates relationship class is made among water pipe feature class and orderly valves and hydrants inside water dataset.

3.3. Analysis of water network system:

3.3.1. Analyzing distribution network:

Arc catalog was used to create the file geodatabase, datasets and the different feature classes. In arc map we added the different feature classes and then we used some of the visualization power of GIS to present the piping system as transmission lines, distribution mains, and service pipes.

Transmission lines used to transfer water from plants to distribution system. Distribution mains used to transfer water to the different city zones, and service pipes used to transfer water to the consumption zones. There are five types of distribution systems in the study area. The first one is complete loops network with service pipes equal to or greater than 200 mm. These networks are concentrated in the industrial zones and in some residential zones (Fig. 3). The second type is loop network with service pipes of 100 mm diameter and main pipes of 200 mm diameter. These networks were found in one residential zone (Fig. 4). The third type is circular network with central mains of 200 mm, surrounding mains of 250 mm and service pipes of 100 mm diameter. These networks were found in most of the residential zones (Fig. 5). The fourth type is circular network with central mains of 150 mm, and service pipes of 100 mm without any surrounding mains. These networks were found in some residential zones (Fig. 6). The fifth type is tree networks with dead ends. These networks were rarely found that can be neglected.

Table 1: Feature datasets and feature classes.

Subtype	Geometry	Type	Feature Class Name
City dataset	Polygon	Feature class	City boundary
	Polygon	Feature class	Land use
	Polygon	Feature class	Residential_areas
	Polygon	Feature class	Buildings
	Polyline	Feature class	Streets
General location dataset	Polygon	Feature Class	Governorate
	Multipoint	Feature Class	Districts
	Polygon	Feature Class	Irrigation_Network
Raw water dataset	Line	Feature Class	Raw_water_pipe
	Point	Feature Class	Raw_water_pumps
Water dataset	Line	Feature Class	Pipe
	Point	Feature Class	water_pumps
	Point	Feature Class	Haydrant
	Point	Feature Class	Reser
	Point	Feature Class	Valve
	Point	Feature Class	water_plant

Fig. 3: Completely loop network with service pipes equal to or greater than 200mm.

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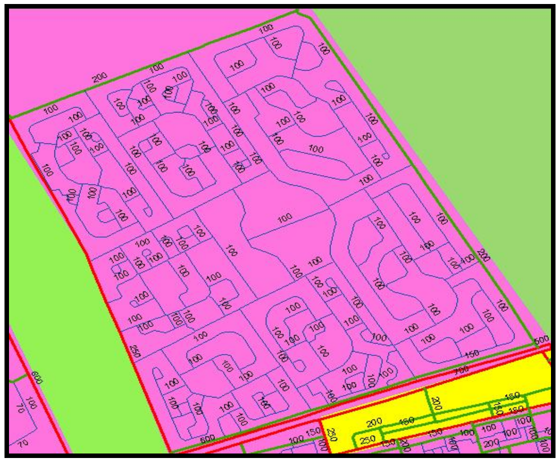

Fig. 4: Loop network with service pipes of 100 mm and surrounding mains of 200mm.

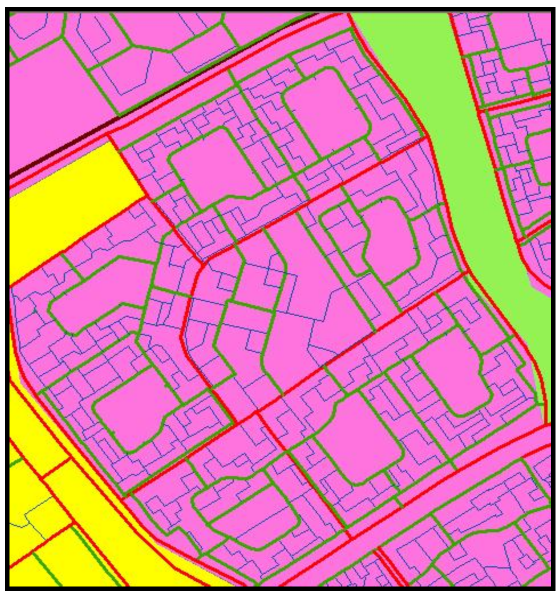

Fig. 6: Circular networks have central mains and service pipes without surrounding mains.

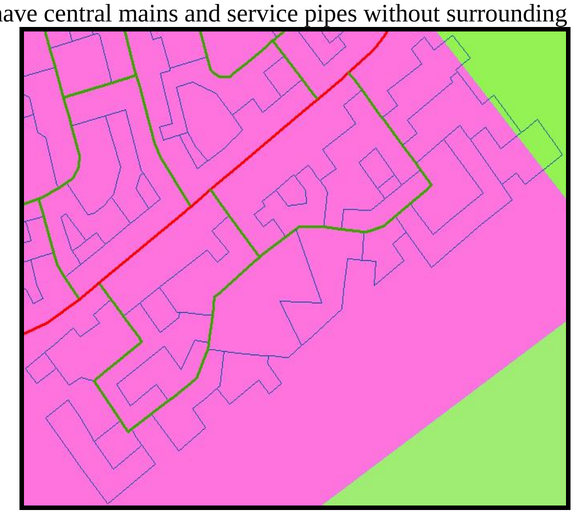

Fig. 5: Circular network with central mains of 200 mm, surrounding mains of 250 mm and service pipes of 100 mm diameter.

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From the previous steps we can prepare an inventory of distribution types for each area. The suggested items of this inventory include area (name, code or address), network type complete loop (diameter, length), central main (diameter, length), surrounding main (diameter, length), and tree (diameter, length).

3.3.2. Analyzing water system using Geometric Network:

A geometric network is a connectivity relationship between collections of feature classes in a feature dataset. Each feature has a role in the geometric network of either an edge or a junction. Multiple feature classes may have the same role in a single geometric network. Arc catalog was used to create the geometric network in the same dataset. Then the created geometric network and the shared feature classes were added to arc map. Then eight tasks were achieved, such as connecting and disconnecting the network features, rebuild and repair connectivity of the network features, verify connectivity of the network features and verify network feature geometry for certain features or for all features.

3.3.3. Analyzing water distribution system using Utility Network Analyst:

In arc map, the utility network analyst was used to achieve many tasks such as: displaying flow directions and define its type (determinate, indeterminate or uninitialized). Studying the connectivity of the network features through achieving many tasks like, find connected and disconnected tasks. The network type and the pattern of distribution have been identified in our network including task of find loops. Performing tracing tasks including trace downstream (Fig. 7), and trace upstream to find all network elements that lie downstream and that lie upstream of a given point. Performing tracing tasks including find common ancestors to find the common features that are upstream of a set of points in our network, find path upstream to find the path from the predefined points to the source, find path to find the path between the features on which we placed flags, and find upstream accumulation to find the total cost of all network elements that lie upstream of a given point.

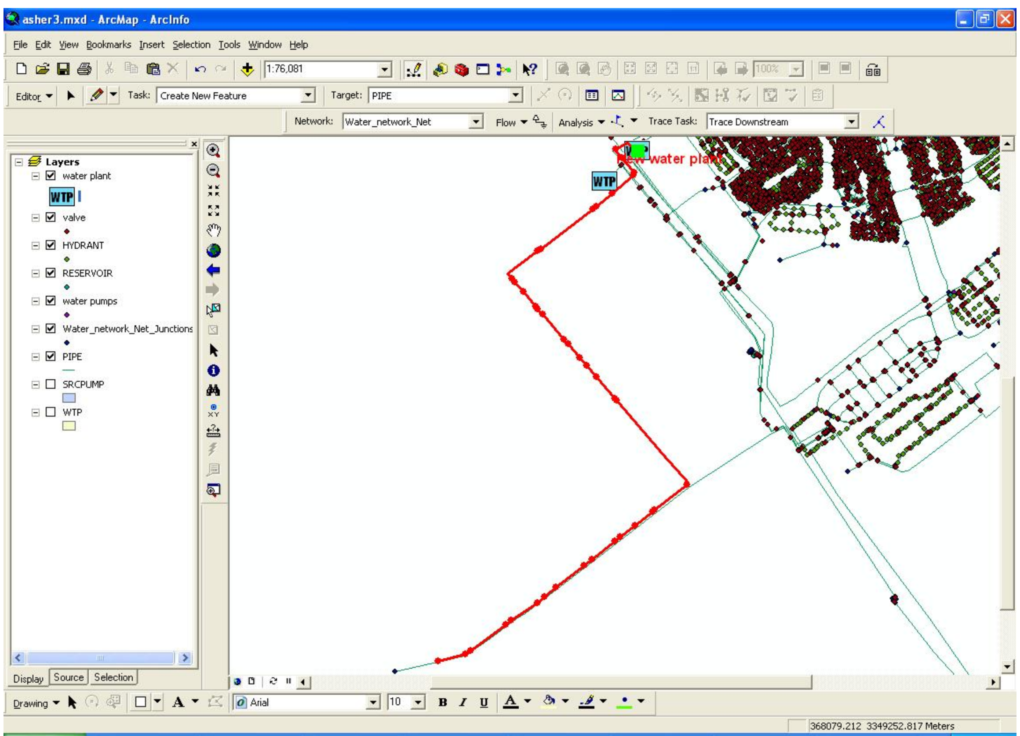

Fig. 7: Trace downstream task to the water plant.

3.3.4 Analyzing water quality:

The study area include more than sixteen districts, only six of them are completely constructed and populated (Fig. 8). Surface water samples were collected from these later districts in order to evaluation of this quality for domestic and industrial uses.

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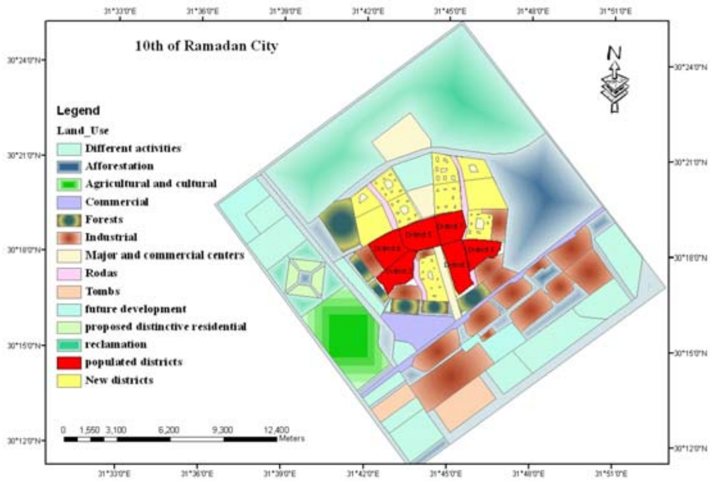
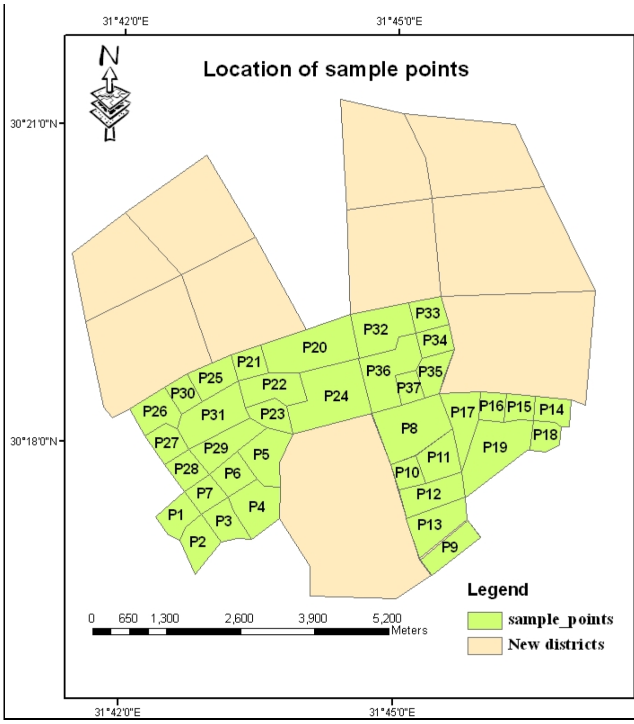


Fig. 8: Location map of study area showing the populated districts.

Twenty seven samples were collected; each sample represents one area (Fig. 9). Four parameters including residual chlorine, turbidity, conductivity, and TDS were measured in the Central Lap of the Greater Cairo Water Company (GCWC). The study reveals that water quality is acceptable for both domestic and industrial uses (Figs 10-11, 12, 13 & Table 2) and the study area can be considered as population attraction area.



The analysis results for the sample points

(After; Central lab of the Greater Cairo Water Company (GCWC)).

district	point_code	residual_CL	Turbidity	Conductivit	TDS
6	P25	1	0.79	412	272
6	P26	1.6	0.83	411	271
6	P27	1.4	0.84	417	275
6	P28	1.3	0.92	413	272
6	P29	1.2	0.7	416	274
2	P1	1.5	0.9	469	309
2	P2	1.4	0.87	466	307
2	P3	1.4	0.87	466	307
2	P4	1.4	0.83	475	313
2	P5	1.4	0.87	467	308
6	P30	0.9	0.74	409	273
6	P31	1	0.81	417	275
2	P6	1.4	0.79	470	310
2	P7	1.4	0.9	466	307
5	P20	1.1	0.89	442	291
5	P21	1.2	0.93	477	295
5	P22	1.4	0.89	408	269
5	P23	1.3	0.91	449	296
5	P24	1.2	0.91	440	290
3	P8	1.1	0.73	409	269
3	P9	1.2	0.7	470	310
3	P10	1	0.7	411	271
3	P11	1.3	0.87	400	264
3	P12	1.2	0.9	404	266
3	P13	1.3	0.77	476	314
4	P14	1.5	0.67	403	266
4	P15	1.3	0.63	405	267
4	P16	1.3	0.58	405	267
4	P17	1.4	0.72	399	263
4	P18	1.3	0.76	398	262
4	P19	1.4	0.69	400	264
7	P32	1.1	0.76	407	269
7	P33	1.3	0.69	410	271
7	P34	1	0.81	209	270
7	P35	1.3	0.78	403	266
7	P36	0.9	0.75	407	269
7	P37	0.8	0.75	412	272

Fig. 9: Location of sample points with there tabular data.

Jens break method has been used for the classification of the four parameters in to three classes (low, medium, high). The results of chemical analysis were presented in arc map as a classification map for each parameter. Classification has been used to classify each district based on the tabular data of each factor.

- The classification of all districts based on residual chlorine indicated that district 2 and large area of district 4 fall in the high class, whereas most of district 7 falls in the low class (Fig. 10).
- The classification of all districts based on turbidity indicated that district 5 falls in the high class, whereas most of district 4 falls in the low class and most of district 7 falls in the medium class (Fig. 11).

- The classification of all districts based on conductivity indicated that district 2 and most of district 5 falls in the high class, whereas the rest districts fall in the medium class except one vicinal which falls in the low class (Fig. 12).
- The classification of all districts based on TDS. The study indicated that district 2 falls in the high class, whereas most of district 5 falls in the medium class .and most of the rest districts falls in the low class (Fig. 13).

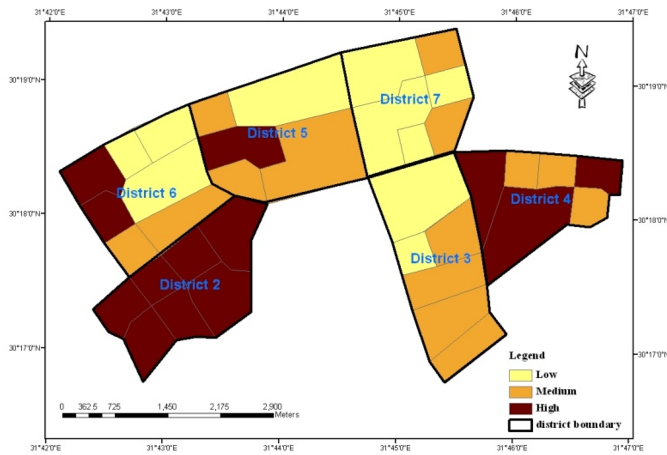


Fig. 10: Residual chlorine classification map.

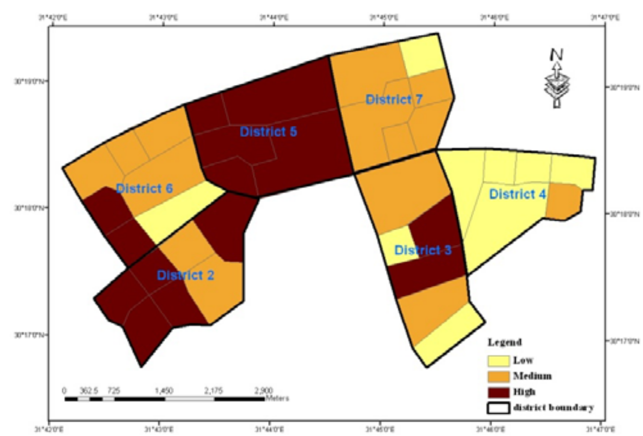


Fig. 11: Turbidity classification map.

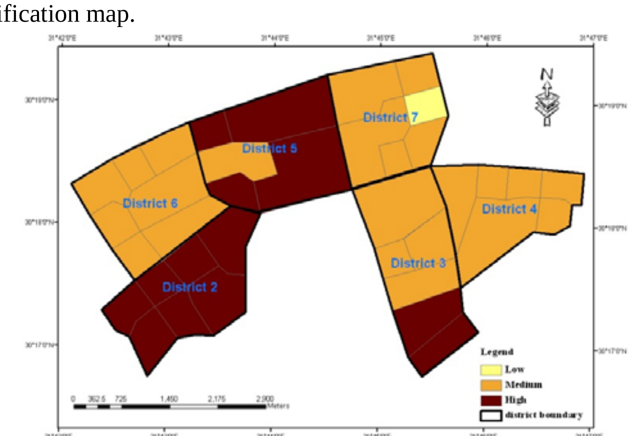


Fig. 12: Conductivity classification map.

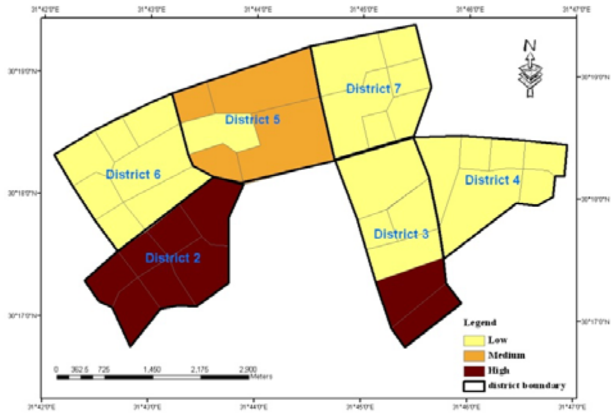


Fig. 13: TDS classification map.

Table 2: Measured parameters compared with the international standards.

Parameter	Max. allowable value	Unit	Max. measured value	Evaluation
Residual chlorine	5	Mg/l	1.6	Acceptable
Turbidity	1	NTU	0.93	Acceptable
Conductivity	Unspecified		477	Acceptable
TDS	1000	Mg/l	314	Acceptable

3.3.5 Analysis of network structure:

Most of the water pipe network made of asbestos material which became forbidden manufactured in Egypt as a result of their negative impact on the health of workers. These pipes were installed before the year 1990. The other pipes were cast – iron (CI), ductile iron (DI), pre-stressed concrete (PC), glass reinforced pipe (GRP), and un-plasticized polyvinyl chloride (UPVC) (Fig. 14). Figure (15) shows the classification of pipes due to its age, very old pipes were installed before 1980 include asbestos ones so I suggest replacing the asbestos pipes by pvc which are available and safe.

Figures 16, 17 and 18 show the classification of old pipes. Different old pipes (very old, old and medium) are classified into three categories due to its diameter. The study suggests changing not only the oldest pipes but also the wider ones.

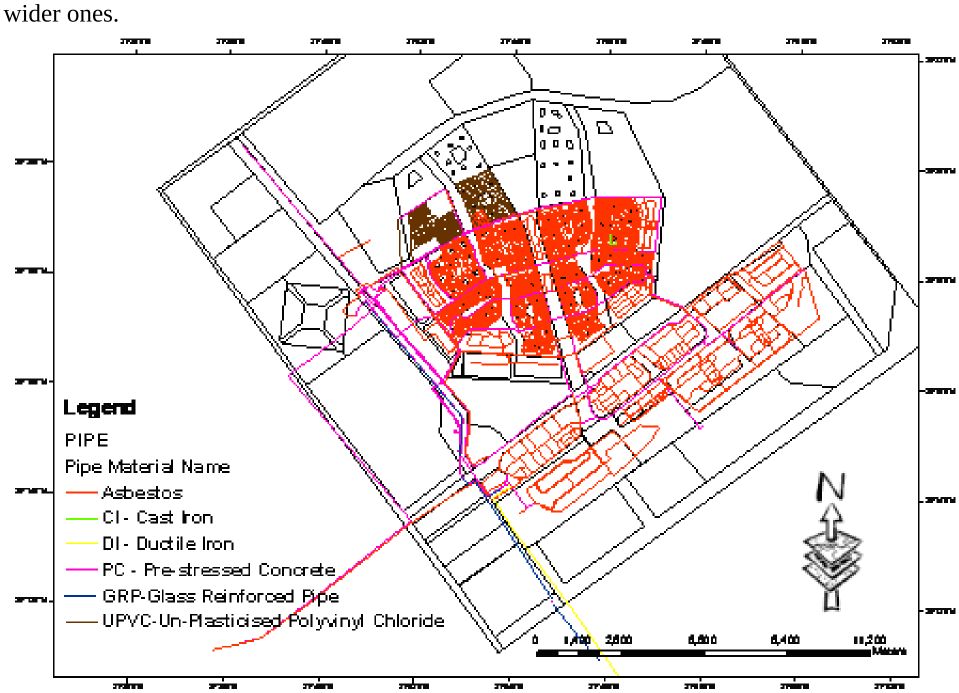


Fig. 14: Pipe material classification map.

Fig. 15: Pipe ages classification map.

Fig. 16: Very old pipes classification map.

Fig. 17: Old pipes classification map.

Fig. 18: Medium pipes classification map.

4. Verification and auditing using topology:

Arc catalog was used to create the topology with the appropriate rules in the same dataset. Then the created topology and the shared feature classes were added to arc map. Then we can correct water network errors. During topology creation, four rules were added. The first rule is that water_pipe must not intersect to ensure that there are no errors resulting from pipe intersection. The second rule is that water_pipe must not have dangles to ensure that there are no unconnected ends in water_pipe. The third rule is that water_pumps must be covered by endpoint of water_pipe to ensure the complete connection between the two feature classes, and the fourth rule is that water_plant must be covered by endpoint of water_pipe to ensure the complete connection between the two feature classes. The error inspector tool from topology tool bar was used to recognize the network errors and correct them.

5. Results:

1. Visualization power of GIS were used to analyze the distribution networks into five types (complete loops network; loop network; circular network with central mains of 200 mm; circular network with central mains of 150 mm, and tree networks with dead ends).
2. Rate of population growth in the developed countries compared to the incisive decrease in the available quantities of produced water forced engineers to rethink in methods used in managing water network components more effectively. A geographic information system (GIS) was one of the successful keys that help in solving the problem.
3. The suggested project will help engineers in water networks operating, managing and developing long term plan for the finances expectations of improving the networks performance.
4. As this system insures monitoring for water networks starting from design passing through different stages and arriving to replacing and in the same time it is helpful in the future expectations and predictions of networks, then analyzing operation from 10 to 40 years can be achieved giving engineers the chance to do modifications and extensions in procedures that insure high efficiency in the operation of networks management.
5. The study revealed a high ability of geospatial database for managing water networks through discovering disadvantages like dead ends, as well as determining network type, network path, and verifying and repairing the connection errors. The study revealed also that most of the network pipes need to be replaced by safe new ones.
6. Geometric Network were used to connecting and disconnecting the network features, rebuild and repair connectivity of the network features, verify connectivity of the network features and verify network feature geometry for certain features or for all features.
7. Utility Network Analyst were used to find the path between the features on which we placed flags, and find upstream accumulation to find the total cost of all network elements that lie upstream of a given point.
8. The study reveals that water quality is acceptable for both domestic and industrial uses and the study area can be considered as population attraction area.

9. Analysis of network structure suggests to replacing the asbestos pipes by pvc which are available and safe and suggests to changing not only the oldest pipes but also the wider ones.
10. The topology tool bar (error inspector tool) was used to recognize the network errors and correct them.

6. Recommendations:

1. Governments in the developed countries have to utilize the advantages introduced from Geographic Information Systems in the field of water distribution management.
2. A table clarifies the priorities and ranks of replacing the asbestos pipes was prepared (table, 3).

Table 3: Priorities and ranks of asbestos pipes replacement.

Category	Priority rank	Pipe diameter (mm)		Total length (km)	no. of pipes	Max. pipe length (m)	Min. pipe length (m)
		from	to				
Very old pipes -before 1980 (1st priority)	1	351	600	32.8	72	1206	0.6
	2	201	350	46.4	226	3305	1.9
	3	100	200	131	925	4606	1.2
Total				210.2	1223		
Old pipes - 1980 (2nd priority)	1	201	450	30.7	277	1722	0.96
	2	101	200	82.8	1312	1121	0.5
	3	90	100	168.7	3038	674	0.26
Total				282.2	4627		
Medium pipes - 1980 (3rd priority)	1	161	300	117	1266	1691	0.52
	2	111	160	58	1012	968	0.89
	3	100	110	136	3550	315	0.9
Total				311	5828		
General total				803.4	11678		

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