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Reducing non-revenue water in Egypt using GIS

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Abstract

Unaccounted for Water, referring to all losses from the water system, illegal or otherwise, frequently exceeds 40% of all water produced. This represents a major strain on utility operations and budgets. A large amount of UFW indicates large losses in the revenue of the utilities. Deficiency in financial resources normally leads to a deficiency in the performance of the utility. This deficiency in performance may affect the operation and maintenance of treatment plants and network components.

The main objective is to reduce UFW rates. The multi-stage systematic process involves measuring water flow, leak detection, installing and fixing meters, reducing illegal connections, and increasing billing and collections, and developing GIS layers and databases for all of them. Another objective is to connect GIS maps with Billing, hydraulic systems, hotline systems, etc.

After choosing a pilot area, we review similar activities, conduct field visits, and hold meetings, prepare the timeline schedule, prepare and implement base maps and the water network, analyze and compare end-line results, and report the results. A high reduction in the UFW percentage is expected due to fixing the discovered leaks.

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1. Introduction

The discrepancy between delivered water and the water paid off to the utility is defined as the unaccounted-for water (UFW). Water delivered to the system could be production or water produced by a water treatment plant (WTP), or water produced from one well or more. It could also be water delivered to a certain network from a regional system connecting two or more areas.

UFW is normally calculated as the percentage of delivered water to the system under consideration. It is then categorized into physical losses and non-physical or commercial losses. Physical losses are typically the water that is physically lost from water treatment plants like the overflow of tanks and washing off, or water lost from the network through leakage of the pipelines. Commercial losses are normally attributed to:

- Metered customers: meter inaccuracy, broken meters, un-read meters, low flow un-registered by the meter, billing error, customers with no records.
- Un-metered legal customers: network flushing, government buildings, religious buildings, public taps, fire hydrants, street cleaning, and parks.
- Un-metered illegal customers: illegal connections, customers with no meters.

This can be applied to a whole network of a system or can also be applied on a small scale to a part of the network called a hydraulic zone. A hydraulic zone is defined as a part of the network feeding a certain area in which the inlets and outlets of that zone are measurable and can be controlled.

2. Problem Formulation

Egyptian water utilities are confronted, on the one hand, with limited financial resources, and on the other hand, with an obligation to provide clean drinking water to consumers. No utilities have been able to recover total expenses based on customer payments; only a few are able to recover operation and maintenance expenditures. Unaccounted for water (UFW), referring to all losses from the system, illegal or otherwise, frequently exceeds 40% of all water produced. This represents a major strain on utility operations and budgets.

A large amount of UFW indicates large losses in the revenue of the utilities. Deficiency in financial resources normally leads to a deficiency in the performance of the utility. This deficiency in performance may affect the operation and maintenance of treatment plants and network components.

2.1. Research Objectives

We developed a methodology for utilities to reduce UFW rates. The multi-stage systematic process involves measuring water flow, leak detection, installing and fixing meters, reducing illegal connections, and increasing billing and collections.

2.2. Methodology

The following steps are the approach of the study implementation:

- Review of similar activities in this field.
- Field visits for follow-up.
- Conduct meetings and presentations
- Establishment of departments and teams for implementation under the guidance of the project advisors
- Maintenance of the water valves in the network and construction of measuring manholes.
- Provide OJT on the use of leak detection equipment.
- Preparation of the timeline schedule
- Selection of a pilot area according to certain criteria.
- Preparation of implementation steps for departments and teams which include the following:

1. Field survey and database preparation with maps for the pilot area by a team composed of GIS staff, meter readers, collectors, and water network maintenance staff.
2. Measuring of water flows and pressures in the pilot area to identify the water consumed.
3. Compete leak detection survey in given area.
4. Encourage fixing of leaks by utility.
5. Measuring of water flows and pressures in the pilot area to identify the physical leakage.
6. Fix and install meters discovered by the database.
7. Replacement of the malfunctioning meters
8. Reduce illegal connections by disconnection or creating billing identity.
9. Combine billing and leakage data under GIS system to track trends and monitor performance against baseline.
10. Orientation of meter readers to get the accurate reading.

- Analyze and compare end-line results in comparison with baseline.
- Reporting and results.

2.3. Pilot Area

This study, shown in Fig 1, is conducted in a pilot area in Luxor city, which is on the west side. The area of it was 0.2 *square kilometers with the following boundaries:*

Fig. 1. Study area.

- Karnak street from the north
- Railway street from the south
- Wheat mill street from the east, and,
- Youssef Hassan street from the west
- It was selected according to the following criteria:
- It should be in the old Luxor city to
- discover many leaks.
- Could be easily identified with clear boundaries.
- Verify small traffic to be easily fixed to fix leaks.
- To be related to a qualified network department
- Low number of connections without meters related to governmental buildings

The Geographic Information System staff built the above-mentioned map for the pilot area from an AutoCAD map and converted it to an Arc-GIS map with the needed information from the field survey as follows, as shown in Fig 2:

Get the data from AutoCAD and the satellite image and convert it into GIS data, then integrate the data and use the same coordinates and projection. Geometric corrections & Geo-referencing of the satellite image by applying the appropriate geometric corrections procedure, utilizing ground control points from topographic maps of the master plan.

Vectorization (drawing maps) is done manually on the screen and sorting the outputs on different layers with the appropriate GIS features representation (House connection – Meters – Pipes- Valves - Valves of Fires- Building - Roads).

Vector data are edited after being transformed to digital form, including error correction and entering missing data. Data is verified visually on the screen. Revisions are made to find out errors, locate missing data, and check for proper features & layer presentation. Digital data is topologically built and prepared to the appropriate GIS format.

Build and implement the data modeling with a database design for the UFW study, then divide the pilot area into grids with unique numbers and prepare maps & sheets to collect data from the field survey.

Digital maps were visually checked in the field, and required attribute data was collected after coding all spatial features in the GIS database to ensure proper spatial links. The database is designed and implemented, then the data model is developed. Various tables were built, including different fields with the appropriate formats, and include all required attribute data.

Quality Control/Quality Assurance (QC/QA) procedures are applied to ensure that proper digital spatial data is developed, attribute data entry, coding, and correct spatial relationship. The data quality measurement and assessment are applied according to: Data Quality, Accuracy, Consistency, and Completeness.

A statistical approach is applied to get an output used in the database analyses.

2.4. Satellite Images

Fig. 2. Satellite Image.

We have satellite images of the region to facilitate the process of mapping, which is in the background, and figures below illustrate satellite imagery, kinds, and accuracy of each one.

We drew roads, buildings, canals, and drains using satellite images to prepare the map for data collection in the second step, as shown in Fig 4. The area is divided into small areas (Grid) to facilitate the process of the small area in the field. Then we grouped these areas using (Index), which is designed by a team working in the GIS program.

Fig. 3. Divide the region into Grids.

In this step, we started the data collection from the field. We measured distances from the field to verify the distances in our maps, which were drawn by satellite imagery. We filled out the forms and drew the water pipes network, valves, and fire hydrants. The figure below illustrates a model of the field survey forms.

2.5. Analysis

We made some statistics for the summation of the amount of water used in cubic meters (Fig. 4).

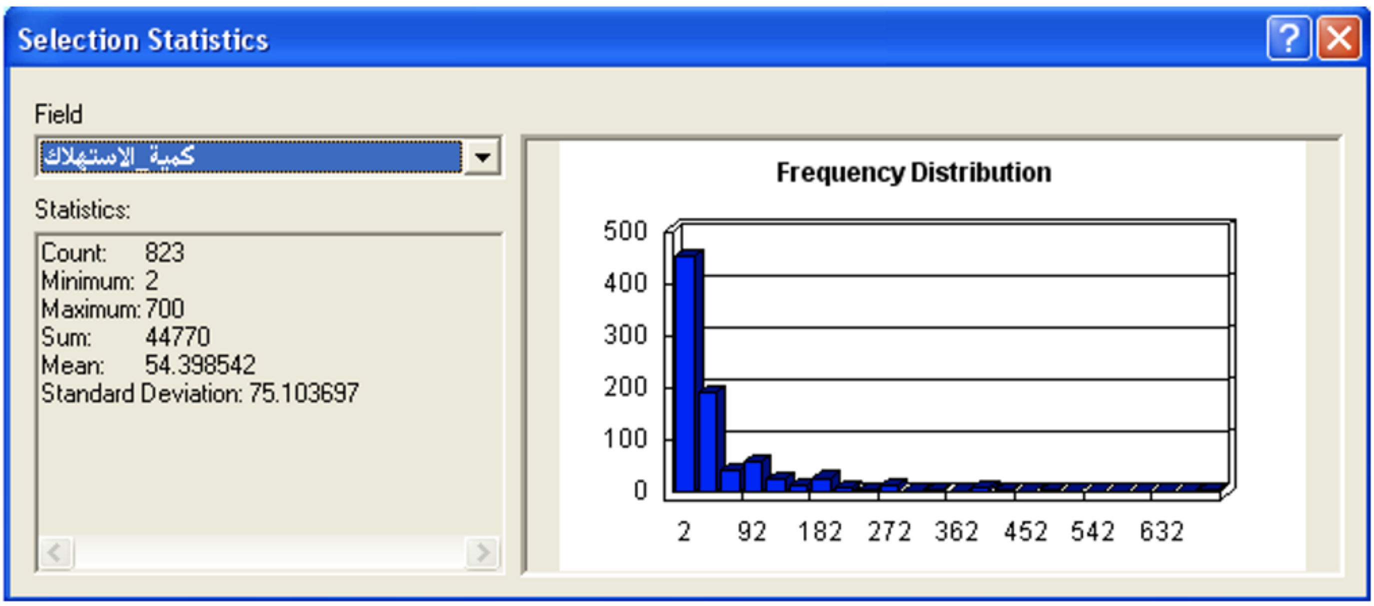

Fig. 4. Statistics of water in cubic meters.

Fig 4: Graph showing the total counters depending on the type of calculation for the months of July and August. Linking the GIS water network with different sections:

By the coding systems, we linked the counters with the billing systems, hydraulic systems, etc.

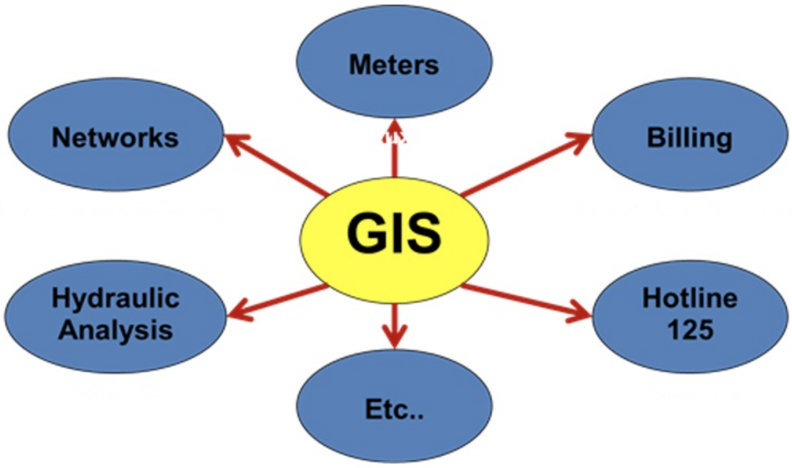

Fig. 5. GIS Links.

3. Problem Solution

- Decrease the redundancy of data.
- Ensure high quality of data and improve the accuracy and safety of geographic information.
- Exchange data efficiently and quickly.
- Integrate GIS applications with other applications.

Formation of the required teams:

The following teams were formed and got on-the-job training to be ready for carrying out the study:

- Meter calibration and repair workshop
- Leak detection and loss reduction staff
- Geographic information system staff
- Meter replacement team
- Team for surveying non-readable meters.
- Illegal connections team

3.1. Water supply

The pilot area is not isolated from the Luxor water network, and there are no bulk meters to measure the supplied water. Three locations were identified to measure the water quantity, two for water in, and one for water out. Three ultrasonic flow meters were installed in the three locations. It was found that the water supplied to the pilot area for 48 hours is 7295 cubic meters before conducting the leak detection process. The average pressure in the network during the flow measurements was (0.77 – 1.9 bars). The estimated population in the pilot area is 13233. So, the water consumed per person per day is 276 liters, which is too much in the rural governorates. This means that there are many sources of physical and commercial leakages.

3.2. Leak detection

A leak detection survey was implemented in the pilot area to discover the leaks' locations. Before that, on-the-job training was done for the leak detection team at Luxor. The discovered leaks in the area were 108 leaks. This figure is too much for a small area (0.2 square kilometers), and this reflects the obsoleteness of the water network. It means that it is better to replace the network if and only if the leaks fixing need more than 50 % of the replacement cost. The discovered leaks were identified and marked to facilitate the work of the network team during the fixing process.

Reduction in the UFW Percentage due to leaks repair:

A second round of measurements has been carried out in the pilot area in the same three locations to know the effect of repairing the discovered leaks. The consumption of water inside the pilot area was found to be 4947 cubic meters for 48 hours, and the mean effective pressure was (1.1 – 2.2) bars. So, the mean of the water consumed is 187 liters per person per day, which decreased by a percentage of 32.2 %.

The following table presents the conclusion of measurements before and after repairing the discovered leaks in the pilot area.

Table 1. Water Measurements

Item	Before repair the leaks	After repairing the leaks
Quantity of water consumed in 48 hours (cubic meters)	7295	4947
Consumption / person / day (liters)	275	187
Mean effective pressure (bars)	1.9	2.2
Lowest pressure (bars)	0.77	1.1
Percentage of UFW	50.18	32.2

So, the UFW after repairing the leaks in the pilot area = 50. 18 - 32.2 = 20 %

3.3. Customers Database

A team composed of Luxor GIS engineers, network technicians, meter readers, and billing center employees carried out a survey for the customers in the pilot area. The database contains customer names, owner names, number of flats in the building, address, length of water connection, meter type, meter diameter, meter status, meter reading, water consumption, etc. The number of customers in the pilot area is 1727 customers after the survey is completed. The current situation of the meters is presented in the following table.

Table 2. Water Customers

Meter status	In operation	Out of order	Less accuracy	Illegal connection	Removed	Total
Available number	1205	287	230	4	1	1727

The total malfunctioning meters are 508 (i.e., the out of order and the Less accuracy reading meters 287 + 230) and those replaced with new meters. Luxor's commercial sector billed those 508 meters with a flat rate of 60 cubic meters per period (two months). Reduction in the UFW Percentage due to commercial activities:

“Luxor” commercial sector formed the metering teams to carry out meter replacement, repair, calibration, illegal connection, and follow up on their work and contributed to the following activities:

- Simplify the work of the meter readers by identifying the accurate route of each reader and redistributing them among the districts and branches.
- Discover the illegal connections and cut the service if the customer did not contract with the company or connect to an adjacent customer and pay the bill together.
- Install meters in the governmental buildings and in the non-governmental connections, or convince them with a suitable flat rate until the installation of meters.
- Survey the big consumption customers, i.e., hotels and commercial activities (factories, ships feeding connections), and take the necessary action to install meters or accept the estimated flat rate.
- Replacement of malfunctioning meters

To identify the reduction that happened in the percentage of the UFW, a comparison was made for the consumption of the 1727 customers (which are in the pilot area) in the period of November and December 2008 with their consumption in the same two months in the year 2009, which is presented in the following table.

Item	Average consumption in the year 2008 (cubic meters)	Average consumption in the year 200 (cubic meters)	Average Consumption increase (cubic meters)
For one customer	52.9	55.3	2.4
For the 1727 customers in one period	91358	95503	4145
For the 1727 customers in one year	548148	573018	24870

Hence, the reduction in the UFW = 24870 / 548148 = 4.5 %

This reduction was due to:

- Correction of meter readings (by redistributing meter readers among branches)
- No errors in entering data in the billing center (by revision of data)
- Issuing bills for the connections which are with meters but not billed.
- Redistribution of accumulated meter readings among the next 6 months
- Repairing of meters with no accurate reading (less than real consumption)

On the other hand, it was considered that there would be a big reduction in the UFW percentage due to the replacement of the malfunctioning meters. But due to the big flat rate (60 cubic meters per connection per period), it was found that there is a reduction in the average consumption of each customer from the (508) replaced meters. This happened when comparing the consumption of the (508) customers in November and December 2008 with their consumption in the same period but in the year 2009. It was found that the average reduction in consumption per connection is 0.913 cubic meters per period. The results gained are presented in the following table:

Table 3. Reduction Table

Item	Average consumption in the year 2008 (cubic meters)	Average consumption in the year 2009 (cubic meters)	Average Consumption increase (cubic meters)
For one customer	52.9	55.3	2.4
For the 1727 customer in one period	91358	95503	4145
For the 1727 customer in one year	548148	573018	24870

Since the 1727 meters include the 508 malfunctioning meters, the decrease in the UFW percentage (4.5 %) will not be affected by the calculations of the replaced meters.

Accordingly, the total percentage reduced in the UFW = 32.2 + 4.5 = 36.7 % due to the leaks repairing and the commercial activities.

So, the UFW in the pilot area after repairing the leaks and doing the commercial activities is:

= 50.18 - 36.7 = 13.48 %

We note that, in fact, the reduction percentage of 4.5 % by the commercial sector is more because of:

- The measurements are made in the winter period (November & December), and it will be increased in the summertime.
- There are a lot of connections without meters and at the same time not billed with a flat rate. This happens in the buildings located in the El-Karnak district.
- The irrigation of gardens and trees in all streets.

Reduction of the UFW percentage in Luxor city: data was gathered from the Luxor water treatment plant, reflecting the production during January and February 2010, i.e., after the end of the UFW program. The plant produced 4483652 cubic meters, supplied to Luxor city only. The billed water to customers for the same period was 3129998 cubic meters. As mentioned, before the pilot program ended in May 2010, so these figures of production and billed water were before that date. The major cause of this is the non-availability of the billed water for the period of March and April 2010 in the billing system. Accordingly, there was no effect due to the repairing of the discovered leaks in the pilot area, which were repaired in May 2010. The major effect was due to the commercial activities, which will be presented later.

Table 4. Reduction of UFW

Item	Average consumption in the year 2008 (cubic meters)	Average consumption in the year 2009 (cubic meters)	Average Consumption Decrease / increase (cubic meters)
For one customer	56.225	55.342	(- 0.913)
For the 508 customers in one period	28562	28114	(- 448)
For the 508 customers in one year	171372	168684	(- 2688)

As mentioned, before, this was because of the following activities, and it happened as a byproduct of the pilot area study:

- Orientation of the meter readers and concentrating on accurate meter reading, reporting for illegal connections, and malfunctioning meters.
- Redistribution of meter readers among Luxor reasons and branches (19 branches).
- Repairing of big leaks and damage in the major water network pipes.
- Replacement of 5382 malfunctioning meters.
- Applying the disconnection policy for illegal connections.
- Taking a decision in the Luxor company board of directors to give the person who reports the new illegal connection; to give him an incentive equal to 0.5 % of the penalty imposed on the illegal connection owner.

4. Conclusion

The UFW percentage was reduced in the pilot area by 32.2 % due to the repair of the discovered leaks.

Also, it was reduced by 4.5 % because of the commercial activities. The total reduction in the UFW percentage in the pilot area was 36.7%.

The present UFW percentage in the pilot area is 50.18 - 36.7 = 13.48 %. At Luxor city, the reduction in the UFW percentage is 30.2 %. The present UFW percentage in Luxor city is 20%

5. Recommendations

Using the handheld device in the meter reading instead of the manual process will decrease errors encountered in the meter readings.

Installing new meters for the governmental and non-governmental buildings that have connections without meters.

Applying an incentive system for Luxor staff.

Installing bulk meters at the outlet of water treatment plants to have accurate production figures.

Orientation of the commercial sector staff (billing, collectors, meter readers, customer service center, and meter repair and calibration workshop)

6. Applying the illegal connection policy (Luxor has 12 persons with the legal authority)

Replication of the study in all Luxor districts (zones) according to the attached program.

Increasing the staff working on the replication of the study in Luxor zones (GIS, leak detection, network staff, and meter repair & calibration workshop).

Statements and Declarations

Funding

No funding was received for conducting this study.

Conflict of Interest

The author has no conflicts of interest to declare that are relevant to the content of this article.

Ethics approval and consent to participate

Approved

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