Reducing non-revenue water in Luxor-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 Unaccounted for Water 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 Unaccounted for Water 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 Geographic Information System layers and databases for all of them. Another objective is to connect Geographic Information System 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 Unaccounted for Water percentage is expected due to fixing the discovered leaks. The issue of Unaccounted for Water, encompassing losses from the system, whether legal or illegal. This places a significant burden on both utility operations and budgets. A substantial volume of Unaccounted for Water signifies considerable revenue losses for the utilities, and the financial constraints often translate into performance deficiencies within the utility. We formulated a methodology aimed at assisting utilities in lowering Unaccounted for Water rates. This structured, multi-stage process includes activities such as measuring water flow, implementing leak detection measures, installing, and repairing meters, minimizing illegal connections, and enhancing billing and collection.

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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. Effective water management necessitates sound water governance, encompassing aspects like water resources, water services, and trade-offs, to uphold the sustainability of water delivery to consumers (Lai, 2016). However, a significant challenge confronting water management in developing countries is the management of high rates of water loss or Non-Revenue Water (NRW), posing challenges in meeting consumer demands. Furthermore, water loss within the distribution system hinders water utilities from maintaining water tariffs at reasonable levels (Frauendorfer & Liemberger, 2010; Lai, 2016). As per Bhagat et al. (2019), citing The World Bank, the distribution networks in most developing countries were reported to experience an annual volume of non-revenue water estimated at 45 million cubic meters.

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. 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 high percentage 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. Methodology

The study implementation involves a comprehensive approach, beginning with a review of analogous activities in the field. This is followed by field visits for ongoing assessments and the facilitation of meetings and presentations. Departments and teams are then established, guided by project advisors. The process includes the maintenance of water valves and the construction of measuring manholes, accompanied by on-the-job training for using leak detection equipment. A detailed timeline schedule is prepared, and a pilot area is selected based on specific criteria. Implementation steps for departments and teams encompass a range of activities, such as field surveys, measuring water flows and pressures, leak detection surveys, and encouraging utility-driven leak fixes. This is followed by the replacement of malfunctioning meters and efforts to reduce illegal connections. Integration of billing and leakage data under the GIS system is undertaken to monitor trends and performance against the baseline. Meter readers are oriented for accurate readings. The study culminates in the analysis and comparison of end-line results with the baseline, followed by comprehensive reporting of findings and outcomes. GIS enables utilities to analyze historical trends in water consumption and losses. GIS is used to integrate meter data into a spatial context. By correlating consumption data with the geographic layout of the distribution system, utilities can identify discrepancies, such as areas with abnormal water usage patterns. This facilitates the identification of potential metering issues and UFW sources. By visualizing and interpreting spatial patterns over time, utilities can identify persistent UFW issues, assess the effectiveness of past interventions, and implement targeted strategies to reduce losses. GIS is employed for managing the spatial information of water network assets. By mapping the locations of pipes, valves, meters, and other infrastructure components, utilities can assess the condition of assets and identify potential points of failure contributing to UFW. This aids in prioritizing maintenance and rehabilitation efforts.

2.2. Study 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:

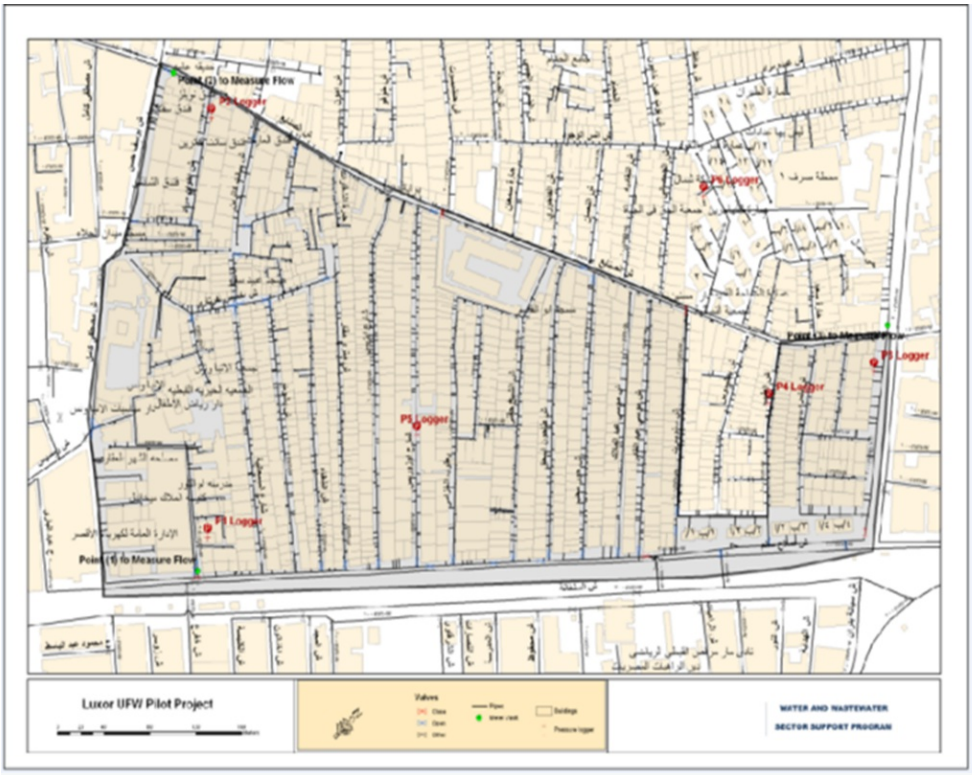

Fig. 1. Study area.

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 red dots are the location of the measurement points.

The Geographic Information System (GIS) team constructed a map for the pilot area using an AutoCAD map, which was then converted into a GIS map. The necessary information from the field survey was incorporated, as depicted in Fig 2. The process involved obtaining data from AutoCAD and satellite imagery, converting it into GIS data, and ensuring consistency in coordinates and projection.

The satellite image underwent geometric corrections and geo-referencing, utilizing ground control points from topographic maps of the master plan. Manual vectorization was performed on-screen, sorting outputs into different layers representing various GIS features (House connection, Meters, Pipes, Valves, Valves of Fires, Building, Roads). The vector data were digitally transformed, edited for errors, and missing data were inputted. Visual verification on-screen was conducted, with revisions made to identify errors, locate missing data, and ensure proper features and layer presentation.

The digital data were topologically built and prepared in the appropriate GIS format. A database design was implemented for the UFW study, dividing the pilot area into grids with unique numbers and preparing maps and sheets for field survey data collection. The digital maps underwent visual checks in the field, and attribute data were collected after coding all spatial features in the GIS database to ensure accurate spatial links.

The database design and implementation involved developing the data model and constructing various tables with different fields and appropriate formats, encompassing all required attribute data. Quality Control/Quality Assurance (QC/QA) procedures were applied to guarantee the development of proper digital spatial data, accurate attribute data entry, coding, and correct spatial relationships. Data quality was measured and assessed based on criteria such as Data Quality, Accuracy, Consistency, and Completeness. A statistical approach was applied to generate outputs for use in database analyses.

2.3. Satellite Images

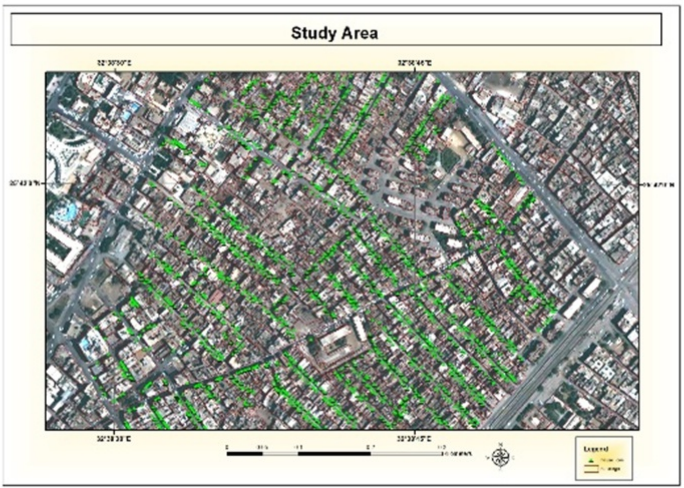

Fig. 2. Satellite Image.

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 survey. 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.

2.4. Analysis

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

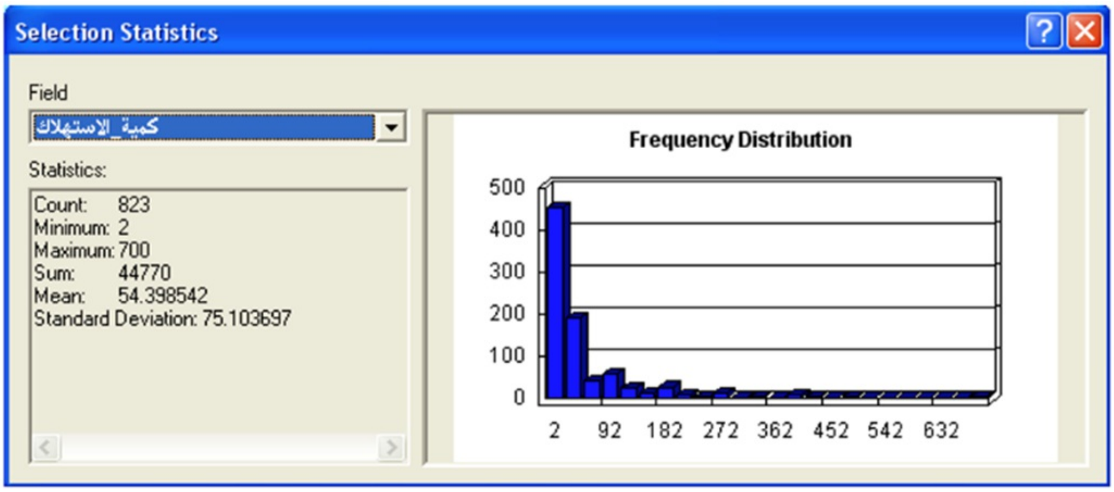

Fig. 4. Statistics of water in cubic meters.

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.

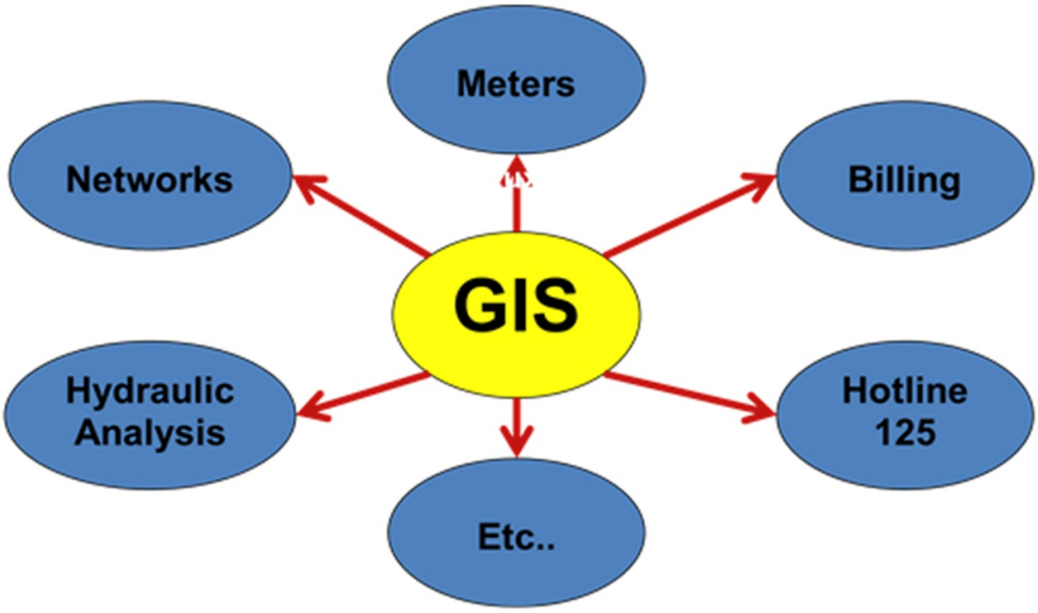

Fig. 5. GIS Links.

3. Problem Solution

Addressing the identified challenges involves implementing the following solutions. Decrease Redundancy of Data: To mitigate data redundancy, a centralized data management system should be established. This system will facilitate the storage and retrieval of data from a single source, reducing duplication. Additionally, periodic data audits and cleanup processes can be implemented to eliminate redundant information.

Ensure High Quality of Data and Improve Accuracy and Safety of Geographic Information, implementing stringent data quality control measures is crucial. This involves regular data validation, verification, and cleansing procedures. Standardized protocols for data entry and updates should be enforced to enhance accuracy. Additionally, incorporating robust backup and security measures will safeguard geographic information, ensuring data integrity and preventing unauthorized access or loss.

Exchange Data Efficiently and Quickly, to facilitate efficient data exchange, the adoption of standardized data formats and protocols is essential. Implementing Application Programming Interfaces (APIs) can streamline the process of sharing data between different systems. Furthermore, establishing a secure and high-speed communication infrastructure will contribute to the swift and reliable exchange of geographic information.

Integrate GIS Applications with Other Applications, seamless integration can be achieved by developing interoperability standards for GIS applications. This involves creating connectors or middleware that enable the smooth exchange of data between GIS and other applications. Collaboration with vendors and developers to ensure compatibility and integration capabilities will enhance the overall efficiency and utility of GIS applications in conjunction with other systems.

To prepare for the study, several teams were formed and underwent on-the-job training. These teams include Meter Calibration and Repair Workshop Team. A dedicated team was established to handle the calibration and repair of meters. This team received comprehensive on-the-job training to ensure proficiency in maintaining accurate metering equipment.

Leak Detection and Loss Reduction Staff Team, another team was formed specifically for identifying and addressing leaks, with a focus on reducing water losses. Members of this team underwent on-the-job training to enhance their skills in efficient leak detection and mitigation strategies.

Geographic Information System (GIS) Staff Team, a team comprising GIS specialists was assembled to manage geographic information. Through on-the-job training, these professionals were equipped with the necessary skills to effectively utilize GIS tools for spatial analysis and data management.

Meter Replacement Team, a dedicated team was established to handle the installation of new meters, particularly targeting governmental and non-governmental buildings with connections lacking meters. On-the-job training was provided to ensure the team's readiness for meter replacement tasks.

Team for Surveying Non-readable Meters, a specialized team was formed to survey and address non-readable meters. On-the-job training was provided to enable the team to identify and rectify issues related to meters that were difficult to read or interpret.

Illegal Connections Team, a team was specifically tasked with addressing and mitigating illegal connections. Through on-the-job training, this team gained the necessary skills to identify and address unauthorized water connections, ensuring the integrity of the water distribution network.

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 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 might be 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 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 2021 with their consumption in the same two months in the year 2022, which is presented in the following table.

Table 3. Average consumption

Item	Average consumption in the year 2021 (cubic meters)	Average consumption in the year 2022 (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 2021 with their consumption in the same period but in the year 2022. 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 previous table.

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

Accordingly, the total 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 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 2021 (cubic meters)	Average consumption in the year 2022 (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

In conclusion, addressing the issue of Unaccounted for Water (UFW), encompassing both legal and illegal losses, is paramount as it often surpasses 40% of the total water produced, imposing a significant burden on utility operations and budgets. Such losses adversely impact revenue and consequently hinder the overall performance of utilities. The primary objective of this study is to mitigate UFW rates through a multi-stage systematic process, involving activities such as measuring water flow, implementing leak detection measures, and addressing illegal connections. Additionally, the integration of Geographic Information System (GIS) maps with billing, hydraulic systems, and other components is pursued. By selecting a pilot area, conducting comprehensive reviews, field visits, and meetings, and meticulously implementing base maps and water network improvements, we aim to achieve a substantial reduction in UFW percentages. The expected outcome involves the successful identification and repair of leaks, contributing to a more efficient and sustainable water utility system. The UFW 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 in the pilot area was 36.7%. The present UFW in the pilot area is 50.18 - 36.7 = 13.48 %. At Luxor city, the reduction in the UFW is 30.2 %. The present UFW in Luxor city is 20%

5. Recommendations

To enhance the efficiency of meter reading, it is proposed to replace the manual process with handheld devices. This transition is anticipated to reduce errors typically encountered in traditional meter reading practices.

Aiming to address connections without meters, a plan is in place to install new meters for both governmental and non-governmental buildings. This strategic measure ensures comprehensive meter coverage, minimizing the potential for inaccuracies in water consumption monitoring.

To motivate and incentivize Luxor staff, an incentive system will be implemented. This system is designed to recognize and reward the efforts of Luxor staff involved in various capacities, fostering a culture of dedication and excellence.

For improved accuracy in assessing water production figures, bulk meters will be installed at the outlets of water treatment plants. This installation will enable precise measurements, contributing to more reliable and transparent water production data.

To ensure the seamless operation of the commercial sector, an orientation program is proposed for staff members involved in billing, collection, meter reading, customer service center operations, and the meter repair and calibration workshop. This training initiative aims to equip staff with the necessary knowledge and skills for effective performance within their respective roles.

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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