Egypt. J. Chem. **Vol. 66,** No. SI 13 pp. 1945 - 1954 (2023)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Chemical properties of drinking water recovered through the application of Pressure Management Activities in Egypt

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Abstract

In the context of bridging the gap between supply and demand in Egypt, this study originated with the aim of Non-Revenue Water "NRW" reduction of networks, by Pressure Management Activities "PMAs", where a District Metered Area "DMA" in Armant in Luxor was considered. This was achieved by inspecting the previous studies in the domain of water loss reduction techniques. In addition, site visits were undertaken; data was assembled; measurements were carried out. The assembled data and measurements were analyzed, from which a complete data picture of the area was perceived. Moreover, a hydraulic model "GEMS" was tooled to simulate the losses in cases with and without PMAs or Pressure Relief Valves "PRV". Results were obtained and contrasted, showing that PMAs reduce losses by 25%. The research recommended that PMAs are efficient for NRW reduction. Moreover, the results emphasized that PMA is a suitable means of saving treated water quantities and costs to serve customers, as it is a suitable substitute for Water Treatment Plants "WTPs".

Key words: Water; Enhancement; Pressure, Management; Leak; Reduction

1. Introduction

Freshwater scarcity is documented worldwide. This is attributed to the fact that it forms 2.5 to 3% of the available water, whereas 1% only is easy to access [1]. In addition, global water volume is constant, while the population is increasing and climate change eliminates this volume due to temperature increase [2].

Likewise, it is the case in Egypt, which has limited water resources and a drastic population increment. Accordingly, water share per capita is decreasing, which necessitates the importance of undertaking an engineering solution to reduce the losses to maintain the per capita share [3].

Freshwater forms 2.5-3% of the global water, 1% of which is easily accessible surface water, 20% is groundwater and 88% is frozen ice [4, 5]. About 70, 22, and 8% of fresh water is utilized for irrigation, industry, and domestic use [6].

In terms of virtual water, the world is trying to replace their eating habits to save it, where 1 kilo of beef, 1 kilo of rice, and 1 cup of coffee needs need 15,000, 1000-3000, and 140 liters of water, respectively [6].

About 98% of Egypt's water resources, such as the Nile River and groundwater basins, originate outside its borders. In fact, the Nile River supplies the country with about 93% of its water needs and this is considered one of the main challenges for water policies, and decision-makers [7].

Many organizations and researchers investigated water resources. World Population Reference Bureau 2017 stated that the limited resources will not meet additional billions of people's needs, by 2050, as the population is expected to be 9.8 billion (i.e., 7.5 billion in 2017). The water resources are affected by the increasing temperatures and climate change, which will lead to droughts and political instability. They called for rapid actions to allocate water in a more rational manner and to consider sustainable techniques

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Receive Date: 28 June 2023, Revise Date: 05 August 2023, Accept Date: 22 August 2023
DOI: 10.21608/EJCHEM.2023.220384.8196

to maintain water security World Population Reference Bureau 2017 [8].

International Water Association (IWA) documented that the MENA region is a fragile and water-stressed region that imposes critical stress on policymakers to safeguard water security through proper water management. Accordingly, they applied techniques to conserve raw water by reducing losses in networks, where the most suitable technique is network pressure management. This technique affects losses and redistributes consumption to achieve optimal use to meet consumers' needs with the least losses. They further added that this amount is 346x106 m3/d, which could supply 800x106 people [9].

International Bank estimated the water losses to be 48.6 x109 m^3/yr and losses in developing countries only could supply 200 x10^6 people. While, the economic value of the annual global losses is 14.6x10^9 \$ [10]. The International Benchmarking Network (IBNET) stated that the world estimate for uninterrupted water levels in developing countries is 40 to 50%. The Central Agency for Public Mobilization and Statistics (CAPMAS) advocated that Egypt's consumption is 89.7 x 10^9 m^3/yr (11, 54.2, 24.5 x 10^9 m^3/yr for drinking, agriculture, and industry. This means that the annual consumption is 560 m^3, which is beneath the water poverty line (i.e. 1,000 m^3/per capita/ year) [11].

1.1. Resources Consumption Losses, the 2021 Production-2050 Water/Capita

Regarding water resources, surface water is provided by the Nile only. It supplies 93% of annual water resources, where Egypt's share is 55.5x10^9 m^3/yr, from which 10x10^9 m^3/yr is lost due to evaporation from the Aswan High Dam reservoir [12]. Moreover, the rainwater is less than 250 mm/yr, where its amount is 1.6 x 10^9 m^3/yr, as Egypt is a desert region with limited rainfall. Additionally, the groundwater is not exploited, although Egypt has immense mineral water resources, where deep groundwater volume is 40,000 x 10^9 m^3, 8% of which is at a depth of 1500 m with deteriorated water quality [13].

Highlighting the water consumption by sector and water balance, the available water is 55.5x10^9 m^3/yr from the Nile, 1.05x10^9 m^3/yr from rainfall along the northern coast, and 6.1 x 109 m^3/yr from groundwater. However, water needs for the different sectors are 89.7x10^9 m^3/yr. This gap is 34.2x10^9 m^3/yr. Accordingly, bridging this gap (i.e. supply-demand gap) is achieved by sea and wells desalination, treated agricultural so as industrial wastewater reuse and losses in networks reduction so as NRW reduction [14].

As for the water losses in 2019-2020 is 3.124x10^9 m^3/yr, this forms 28.4% of drinking water, which is 11x10^9 m^3/yr, CAPMAS. They stated that every 1% lost is 11x10^9 m^3/yr, and its selling price is 2.2 x 10^9 L.E./yr and is equivalent to water savings for 1x10^6 capita/yr. Accordingly, water loss reduction in networks is of significant importance, where pressure management should be utilized to reserve the amount of available freshwater resources and achieve appropriate and fair service for consumers. This is attributed to the fact to the expected reduction in water share per capita [11].

Focusing on 2021 water production, it was 11 x 10^9 m^3/yr and the production of surface water plants was 9.8 x 10^9 m^3/yr (i.e. 89.1%), whereas, the well production is 1.1x10^9 m^3/yr (i.e. 10%). On the other hand, desalinated water is 0.1x10^9 m^3/yr (i.e. 0.9%). However, the per capita share is 110 m^3/yr, whereas the global per capita share is 1385 m^3/yr [15, 16].

Converging on the 2050 expected water per capita, clear was that the population is increasing and water resources are limited, as it is a dry area with limited rainfall. In 2018, the annual share per capita was 550 m^3 and is expected to be 330 m^3 by 2050, which is lower than the water poverty line (i.e. 1,000 m^3) [17].

2. Research Objectives and Methodology

The primary objective of the research work is to bridge the gap between supply and demand by reducing the NRW of the network (i.e., reducing losses) while improving cost, time and level of service, through the implementation of PMAs.

Converging on the research methodology, previous research in water loss reduction techniques was amassed and investigated. A DMA in Armant was selected to be investigated. Site visits were carried out; data was amassed and measurements were undertaken. The amassed data and measurements were inspected, from which a data picture of the area was reflected. "GEMS" was tooled to mimic the losses before and after implementing PMAs or PRV. Results were attained and compared, from which conclusions were deduced and recommendations were suggested. The planned methodology is presented in the Figure 1, where the methodology sequence is presented, as follows:

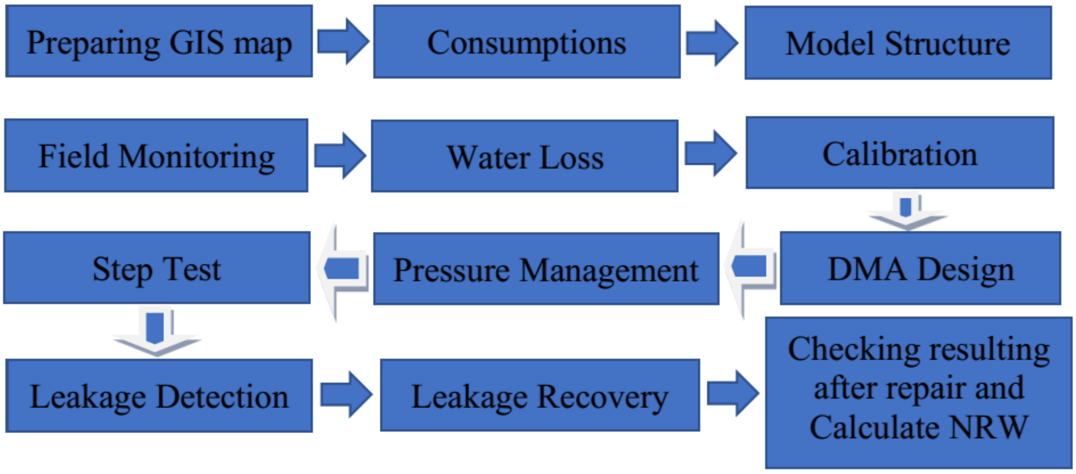


Figure 1: Leakage Detection Methodology scheme

2.1. Site Visits and Site Description

Several site visits were done to Luxor Governorate. The data were gathered and measurements were achieved. About 16 pressure measuring points were allocated and flow meters were installed at the 2 inlet pipes. Field monitoring was carried out. In addition, data and measurements were scrutinized, from which obvious was the following:

- Egypt is confronted by drinking water losses from its networks (about 46.9 % in 2017), where "WTP" treats 103.6 m^3/yr, in 2017. These losses affect the 3434 km long network's performance and efficiency.
- The losses affect service level, revenues, and cost required for operation and replacement, where potable water production cost is 8.6 x 10^6 Euro/yr.
- In 2017, the Holding Company for Water and Wastewater "HCWW" in cooperation with European Union's European Neighborhood Instrument Water Sector Reform Program "EUNIWSR" developed a leakage reduction strategy, where its implementation costs 10 x 10^9 L.E (i.e. 2017 prices).
- HCWW strategy will achieve a saving of 1.2 x 10^9 L.E in production costs (i.e. 2016 prices), leakage reduction from 36 to 20%, and abstraction saving of 1500 x 10^6 m^3 /year by the implementation of 8000 Sustainable savings (DMAs).
- However, these actions need 10 years to be achieved.
- Armant DMA was created during an earlier project, where it was not ideal, as it has two inlets and two networks (i.e. an old network with 200 mm pipe and a relatively new network with 300 mm with few interconnections).
- Armant DMA network has relatively low operating pressures, although it is located near the pumping station. However, some valves were closed, in an attempt to resolve low-pressure problems.

2.2. Hydraulic Modelling (GEMS)

Based on the assembled data, GEMS hydraulic model was tooled to mimic Armant DMA to detect leaks.

"GEMS" is an easily comprehensive tool to support decision-makers in the field of water distribution networks. It improves knowledge about network behavior and how it responds to different operation strategies within the population growth under increasing demands. Its latest copy is version 10.01-01.04 software. It is Cloud Based.

2.3. GEMS Theoretical Background

GEMS utilizes the pressure-flow-deviation method in leak detection together with mass- balance method to detect a full-time leak for a wide range of operating conditions.

"GEMS" allocates the leaks and their sizes. However, this method assumes that the calculated pressure and flow (i.e. of steady-state models or transient models) are equal to measured values if the pipeline has no leaks. However, a leak is confirmed, if there is a deviation between the two.

2.4. GEMS Calibration

GEMS was calibrated against the undertaken measurements during the field visits (i.e. hydraulic and head loss measurements). The results were plotted on graphs, where Figure 2, is given as a sample of the obtained calibration results, from which clear was GEMS capability in mimicking the Armant DMA network.

2.5. GEMS Simulations before PMAS Implementation

Confident with the calibration results, GEMS was tooled to simulate Armant DMA before PMAs implementation, where Armant district is an isolated network with WTPs; Figure 3. In addition, GEMS simulations encompassed several tests (i.e., Minimum-Night-Flow Test, Step Test, Zero- Pressure Test).

Armant simulation and updating were achieved. Primarily, Armant was simulated, where the inputs and exits pipes, diameters were 8 and 12 inches, respectively. Then, the feeding network, at Armant DMA, was updated by the ARC GIS program by extracting the model structure from GIS with 200 mm Asbestos Cement "AC' and 300 mm PVC pipes.

A Zero Pressure Test was carried out to make sure that the Armant zone is an isolated area. Then Armant DMA water feeding network and source were simulated; Figure 4, where the pressure measurement points were allocated at the two inlet pipes; Figure 5. GMS was operated and meter reader paths were so as consumptions were predicted, where GIS and the commercial sector were incorporated. It is to be noted that consumption allocation was achieved by meter reader route-consumption/nodes route, where GEMS determined NRW ratio by utilizing commercial data of bills and inflow quantities

A step test was achieved and the critical zones of DMA were selected; (Figure 6), where the results are presented in Figure (7). The survey was beginning with whereas 3 steps > 50% of losses.

In addition, GEMS designated the Minimum Night Flow Test and the real leakage was estimated.

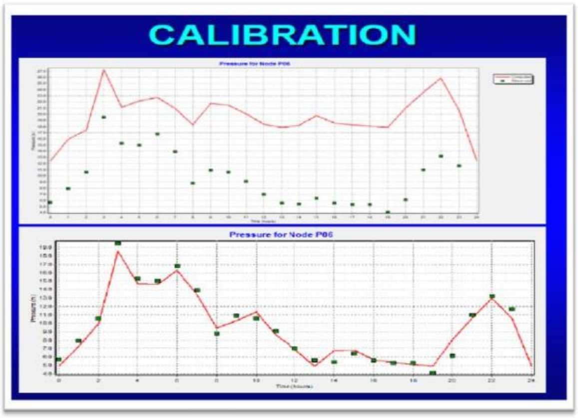


Figure 2: The GEMS calibration results

Figure 3: Armant district with its isolated network

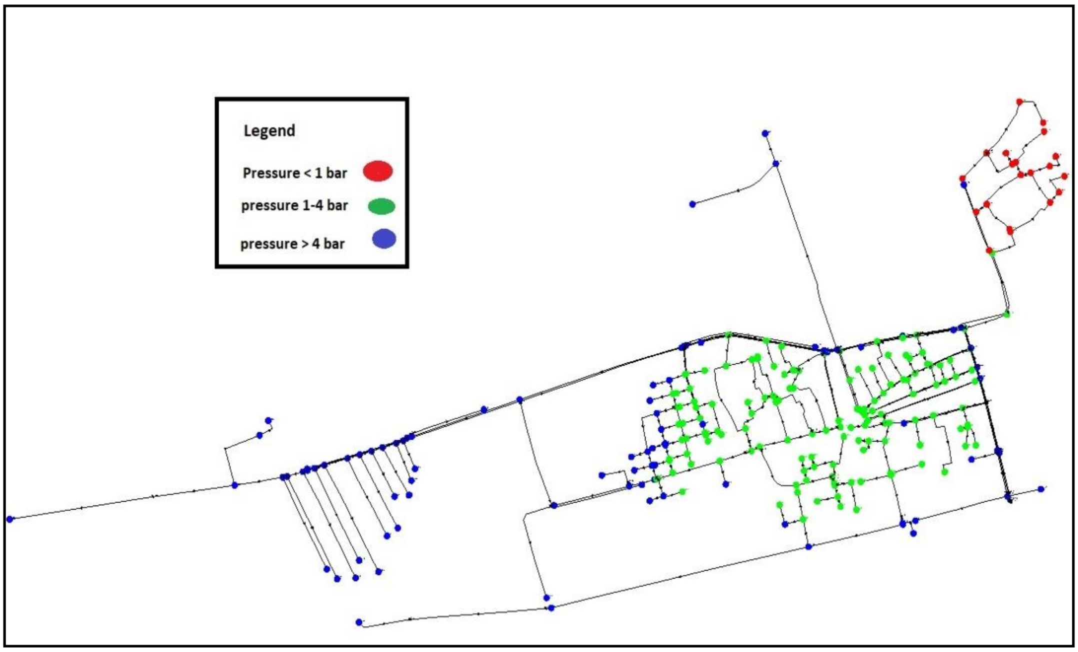
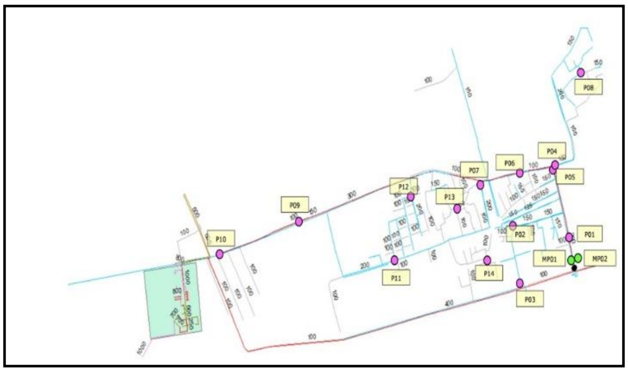


Figure 4: Simulating Armant DMA network – Pressure before PMAs



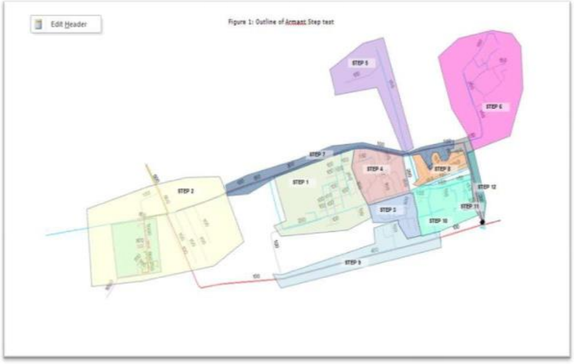


Figure 5: Locations of the 16 pressure measurement points   Figure 6: Step test sub-zones

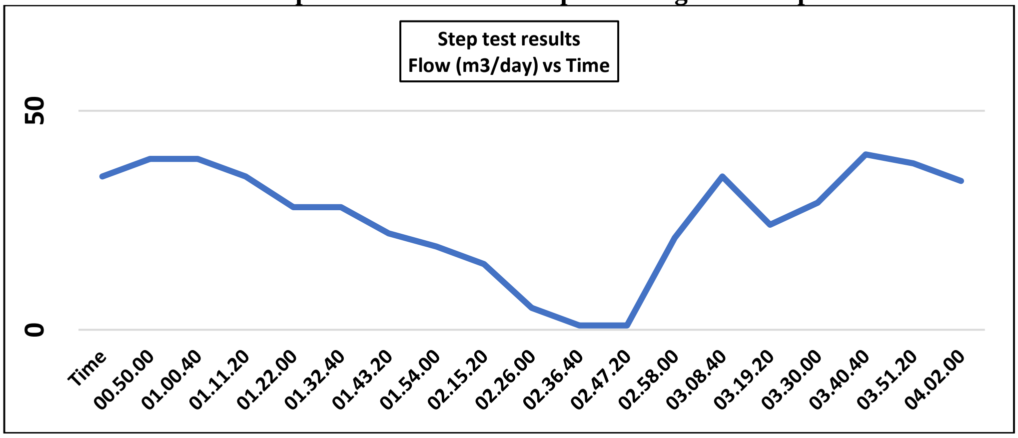


Figure 7: Step test results

2.5 GEMS Simulations after PMAs Implementation

"GEMS" was tooled to simulate Armant DMA after PMAs implementation. The hydraulic model connections between pipes were carried out, where the pressure was redistributed in the network. In addition, a single inlet to the DMA was considered, where a PRV was installed to the control pressure.

GEMS was run after some Engineering interventions, where Table 1 is provided to list these interventions and Figure (10) presents their locations.

In addition, PRV was used at the inflow pipe to control the pressure so as to reduce the excessive pressure, where Table 2 is provided to list the utilized PRV characteristics.

Results were obtained and analysed, from which clear was that the implementation of PMAs achieved better pressure distribution.

Leakage detection and repair was achieved and NRW (i.e., losses ratio) was determined by implementing commercial data of bills and inflow quantities, where the impact of using connection pipes and PRV was evident, as leakage was reduced and water was effectively saved.

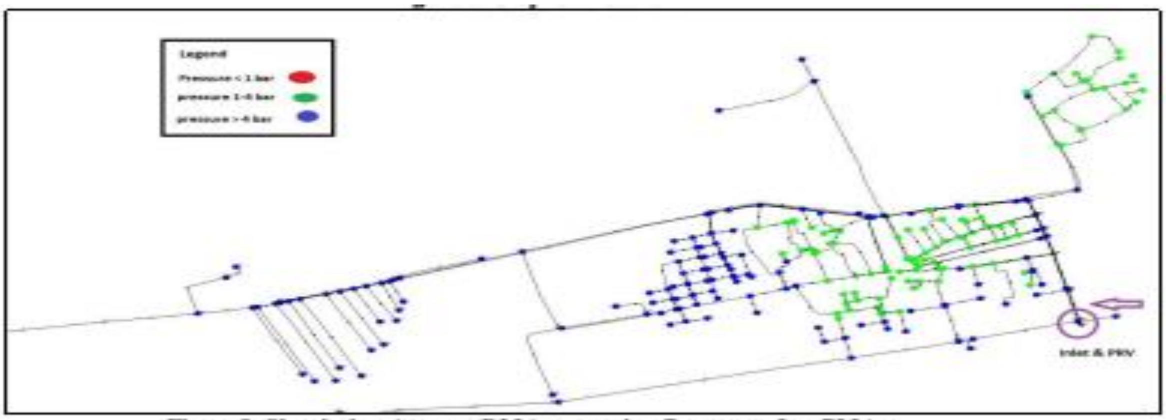


Figure 8: Simulating Armant DMA network – Pressure after PMAs

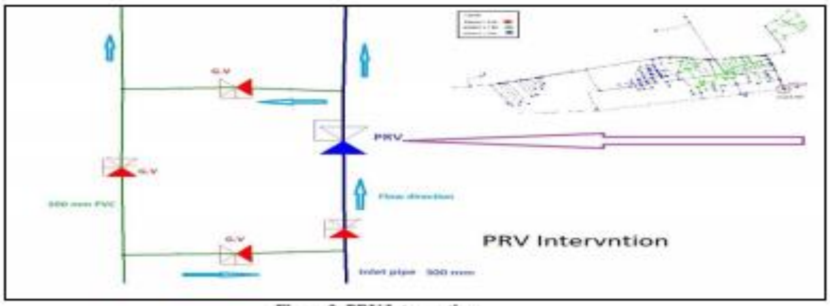


Figure 9: PRV Intervention

Figure 10: Locations of PMAs

Table 1: Implemented interventions

Name	Intervention		Diameter (Mm)	Length (M)
	Number	Description		
PP2	2	New Pipe	150	2
PP5	3	New Pipe	150	2
PP9	4	New Pipe	150	2
Valve3	1	PRV	200	-
PP10	1	New Pipe	200	3
P295	1	Close Valve	200	-
P13	-	Open Existing Closed Valve	200	-

Table 2: PRV Characteristics

Period	Component	Units	Value
NIGHT	Flow	l/s	35
	Upstream (U/S) Pressure	m	35
	Downstream (D/S) Pressure	m	16
DAY	Flow	l/s	72
	Upstream (U/S) Pressure	m	20
	Downstream (D/S) Pressure	m	16

3. Results and Discussion

3.1. The pH, EC and TDS

GEMS results were analyzed. The results indicated that PMAs were not easily to be implemented; they improve water efficiency; reduce water leaks; improve network efficiency and lower operating so as maintenance costs. They encompass PRV and additional electronic or hydraulic control device. In addition, the results indicated that leakage was driven by pressure, where at higher pressure, leakage increases. Accordingly, reducing water pressure during low demand decreases water leakage, while considering consumers and firefighting.

3.2. PMAs Utilization

GEMS results, before PMAs implementation, were analyzed and presented on Figure 11 and Table 3. It was noted that before PKAs implementation, Armant network length was 20.3 km, the losses in Armant rural area were 27% and its average feeding water quantity was measured as 65 l/s.

The results of GEMS, after PMAs implementation, were inspected and provided in Figure 12 and Table 3. The implemented 4 cross connections ensured a single inlet to the DMA and redistributed pressure along the network. In addition, it indicates that the inlet-permeable PRV adapts to the stream pressure during the day and night. Furthermore, results designated that PVAs maintain a pressure, which is equal to minimum pressure at critical points (i.e., 16 m), whereas the closed valves were opened. Furthermore, the average pressure decreased by 25%, and the current display nature has high contrasts.

After implementing the PMAs, the leak was measured. It was 49 l/s, and became 65l/s, before PMAs utilization. This signifies that PMAs implementation daily saved 16 l/s. This means that PMAs saved 41472 and 497664 m^3/d monthly and annually, respectively. The annual saved water will be 1.29 x 10^6 L.E m^3/d potable water. Moreover, after PMAs utilization, the leaks for Armant rural pilot area were 3% in contrast to 27% before their utilization. Kanakoudis and Gonelas (2016) found that, management of water pressure could reduce the leakage of water [18]. This finding was in good agreement with that obtained in this study.

3.2. Chemical Characteristics of the Non-Revenue Water

Table 3 shows the quality of the non-revenue water effluent. The total and fecal coliforms were 9.2 X 10^2 and 6.9 X 10^2 MPN/100 ml, respectively. Consequently, the non-revenue water was fed again with the influent raw water to be further treated. The total and fecal coliforms were reduced to <1. The TDS was increased from 189 to 194 while the turbidity was reduced from 1.6 to 0.2. this is attributed to the addition of the coagulant. The chlorides level was 22 mg/l. the total and fecal coliform counts were reduced from 9.2 X 10^2 and 6.9 X 10^2 to <1 MPN/100 ml. The treated water was found to be complying with the National regulatory standards for drinking water.

3.3. Benefits of applying such Technique

Table 4 shows the benefits of applying the PMAs technique. This technique reduces the consumption of electrical power, alum, chlorine, oil, and fuel. This was achieved by saving 1382.4 m^3/day of fresh water. This amount constitutes around the consumption of 9216 p.e. this will prevent the raise of water table due to the leakage of such water, and the deterioration of the pipelines. The water loss in Egypt is about 28.4% which is lower than that in Jordan (50%) [27]. The non-revenue water averages in India ranging from 19% to 50% [28].

Table 3: The chemical characteristics of raw and the treated non-revenue water effluent

Parameter	Unit	Collected Non-Revenue Water	Effluent	Ministerial decree 457 / 2007 for drinking water quality
pH		8	7.75	6.5 - 9.2
Turbidity	NTU	1.6	0.2	--
EC	µS/Cm	287	294	--
TDS	mg/l	189	194	500 - 1200
Alkalinity (total)	mg/l	130	120	--
Alkalinity (bicarbonate)	mg/l	130	120	--
Alkalinity (carbonate)	mg/l	0	0	--
Chlorides	mg/l	14	22	200 - 600
Total Coliform	MPN/100 ml	9.2 X 10^2	<1	--
Fecal Coliform	MPN/100 ml	6.9 X 10^2	<1	<1

1- *Average Electricity consumption per Produced water Cubic meter equal 0.4 KWh per Cubic meters.*
2- *Average Alum dose per Produced water cubic meter equal 40 ppm per Cubic meters.*
3- *Average Chlorine dose per Produced water cubic meter equal 7 ppm per Cubic meters.*
4- *Average Cubic meter from Oil Produce 11.40 KWh.*

4. Conclusions and Recommendations

Based on the analyzed results, the following conclusions were deduced:

- PMAs are suitable for NRW reduction and a suitable mean to bridge the gap between supply and demand. They save potable water quantities and cost, in terms of constructing new WTPs.
- PMAs improve water efficiency; reduce water leaks, improve network efficiency.
- PMAs reduce water losses by 25%.
- Before PMAs implementation, Armant DMA average feeding water quantity was 65 l/s, while after PMAs implementation it was 49 l/s.
- The water quantities before and after PMAs implementation indicated a daily saving of 16 l/s (i.e. monthly saving of 41,472 m^3/d) or (annual saving of 497,664 m^3/d). This means that 1.29 x10^6 L.E. are saved annually.
- Before implementing PMAs, Armant DMA rural area losses were 27% in its 20.3 km long network, but after PMAs implementation, losses were reduced to 3%.

Based on the deduced conclusions, the following recommendations were suggested:

- Implement PMAs as they are appropriate methods for NWR reduction;
- Utilize PMAs as they are suitable techniques for saving potable water.
- Employ PMAs as they are proper procedures for saving cost.
- Achieve PMAs as they are appropriate practices that could substitute WTPs.

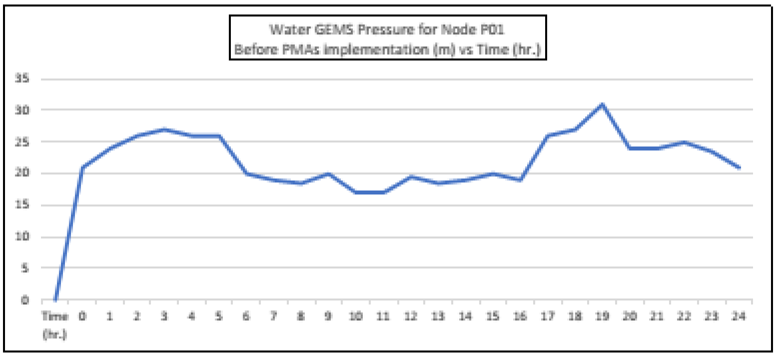


Figure 11: GEMS pressure results (before PMAs implementation)

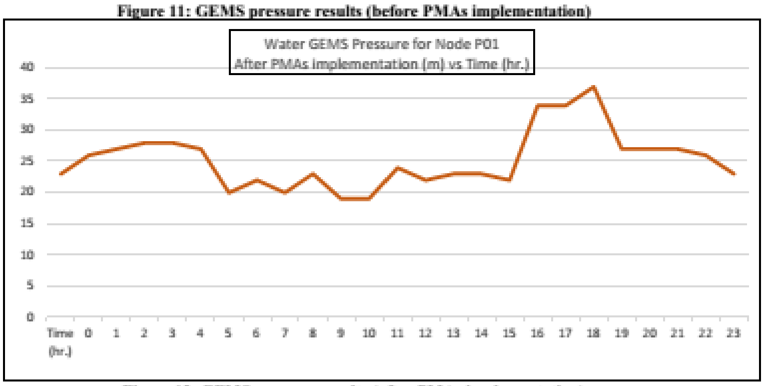


Figure 12: GEMS pressure results (after PMAs implementation)

Table 4: The benefits of applying the PMAs technique

Period	Saved Water (m^3)	Saved Electrical Power[1] (Kw)	Saved Amount of Alum [2] (Kg)	Saved Amount of Chlorine [3] (Kg)	Saved Amount of Oil [4](m^3)
Daily	1382.4	13271	55.3	9.67	48.5
Annually	497664	4843930	20.2	3.53	17702.5

1- *Average Electricity consumption per Produced water Cubic meter equal 0.4 KWh per Cubic meters.*
2- *Average Alum dose per Produced water cubic meter equal 40 ppm per Cubic meters.*
3- *Average Chlorine dose per Produced water cubic meter equal 7 ppm per Cubic meters.*
4- *Average Cubic meter from Oil Produce 11.40 KWh.*

Table 5: GEMS pressure results (before PMAs implementation)

Time (hr)	Pressure (m)	Time (hr)	Pressure (m)
0	21	13	18.5
1	24	14	19
2	26	15	20
3	27	16	19
4	26	17	26
5	26	18	27
6	20	19	31
7	19	20	24
8	18.5	21	24
9	20	22	25
10	17	23	23.5
11	17	24	21
12	19.5		

Table 6: GEMS pressure results (after PMAs implementation)

Time (hr)	Pressure (m)	Time (hr)	Pressure (m)
0	23	13	22
1	26	14	23
2	27	15	23
3	28	16	22
4	28	17	34
5	27	18	34
6	20	19	37
7	22	20	27
8	20	21	27
9	23	22	27
10	19	23	26
11	19	24	23
12	24		

5. Conflicts of interest

The authors declare that “There are no conflicts to declare”.

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