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Effect of Pipe Material and Size on Water Losses at Different Networks in Egypt

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study was done in an attempt to reduce the percentage of losses in water treatment plants and networks by reducing its possible causes.
Study Design: There are many causes for losses in water treatment plants and networks like water lost in water treatment plants due to washing filters and reservoirs, and water lost in networks due to the lack of maintenance or failure to renew ageing systems, illegal connection, metering errors, or accounting errors.
Methodology: Data were collected for Damietta governorate, Egypt. The data collected include types of water treatment plants, capacity, water sold, losses for each water treatment plants and for networks losses, materials and diameters of pipes.
Results: The interrelationships between types of water treatment plants, capacity, Quantity of water sold, losses, materials and diameters of pipes were studied, graphically represented, analyzed, and discussed in order to recommend the proper ways for reducing the losses.
Conclusion: The study concluded that the developed compact water treatment plants is more preferred than surface water treatment plants as it reduced the percentage of losses by 2.5%

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compared to that of surface water treatment plants. The percentage of losses decrease with increasing the percentage of PVC, Cast-iron and GRP pipe lengths to the total lengths of all pipes. The percentage of losses increase with increasing the percentage of asbestos and steel pipe lengths to the total lengths of all pipes.

Keywords: Non accounted-for water; water losses; pipe size; pipe material; water metering.

1. INTRODUCTION

Water is at the precedence of the resources that have a direct impact on various aspects of economic and social growth for various uses in agriculture and industry as well as provide the society with safe drinking water [1-3]. The problem at hand these days is the water shortage problem. The continuous loss in water is one of main causes for water shortage. Water losses is a phenomenon frequently observed within water distribution systems [4]. Losses are apparent in tow branches. The first is the losses in water treatment plants and the second is that in networks. The water is, usually, lost in the water treatment plants due to washing the filters and reservoirs, loose connections and fittings, and poor maintenance of aged tanks [5]. On the other hand, water is, usually, lost in distribution networks as a result of Poor network connections, poor maintenance, illegal connections and unaccounted-for water like governmental and public water usage or inaccurate metering encounter [6]. In general, unaccounted-for water (UWF) is the difference between supplied water from distribution system and leaves water from system to use [7]. UFW may be defined as the percentage of produced water from the raw water source which is not accounted for [8,9]. The loss control methods can be categorized into losses evaluation technique; losses detection technique; and losses control technique [10,11].

2. METHODOLOGY

Data collected for this study for Damietta governorate the data collected include types of water treatment plants, capacity, water sold, losses for each water treatment plants and for networks losses, types and diameters of pipes. The interrelationships between types of water treatment plants, capacity, water sold, losses, types and diameters of pipes were studied, graphically represented, analyzed, and discussed in order to recommend the proper ways for reducing the losses.

This included the relation between type of treatment technology used and the average percentage of losses in these plants. Also, the relationships between the percentage of losses in a network versus the percentage of lengths of every pipe material, such as Asbestos, PVC, GRP, cast iron, and steel pipes were presented. The relationships between pipe diameter and losses were, also, investigated. A serious discussion for the results was discussed, proper conclusions were drawn, and various recommendations were suggested.

3. RESULTS AND DISCUSSION

Damietta governorate contain 19 different water treatment plants which, namely, were Damietta, El-Bostan, Kafr Soliman, El-Adalia, Farskor, El-Roda, El-Serw, Shrabas, Meet Aboghali, Kafr Meet Aboghali, Kafr El-Shenawi, El-Adalia El-Modaga, Kafr El-Batikh1, Ezbat El-Nahda, Dakhala1, Kafr El-Batikh 2, Kafr El-Maiasra, Dakhala2, and El-Rahamna. The percentage of average losses throughout Damietta governorate is 26.43%. According to The Holding Company for Water and Wastewater (HCWW), this percentage of losses includes 16.54% in networks losses, which are due to lack of maintenance, failure to renew ageing systems, illegal connection, metering errors, or accounting errors which are often more significant. The losses, also, includes 9.89% in water treatment plants losses.

Table 1 represents the relation between water treatment plants, capacity, water sold, and losses according to HCWW. The average losses in all water treatment plants is 10.63%, while the standard deviation (STDEV) of the losses data set is 4.59%. No plant losses exceeded the mean value of water losses ± (2×STDEV). The same relation is presented by Fig. 1. The figure shows the relation between different water treatment plants in Damietta governorate on X-axis versus the capacity, water sold and losses on Y-axis, where losses (m3/day) is the difference calculate between capacity (m3/day) and water sold (m3/day).

Table 1. The losses in water treatment plants as the difference between capacity and water sold in Damietta governorate

Water treatment plant	Capacity	Water sold	Losses	Percentage of losses
	m3/d	m3/d	m3/d	%
Damietta	29453.76	25073.28	4380.48	15.00
El-Bostan	45452.80	42725.80	2727.00	6.00
Kafr Soliman	131664.96	100785.60	30879.36	23.50
El-Adalia	66165.12	58966.90	7198.20	11.00
Farskor	3164.04	2841.30	322.70	10.20
El-Roda	71678.35	67019.41	4658.94	6.50
El-Serw	4717.35	4389.60	327.60	6.95
Shrabas	2544.30	2138.40	405.90	16.00
Meet Aboghali	12587.18	11388.88	1198.30	9.52
Kafr Meet Aboghali	21293.92	19121.94	2171.98	10.20
Kafr El-Shenawi	20409.23	19082.63	1326.60	6.50
El-Adalia El-Modaga	2325.51	2181.90	143.50	6.20
Kafr El-Batikh1	24344.10	23216.40	1127.60	4.70
Ezbat El-Nahda	4008.51	3422.40	586.08	15.00
Dakhala1	11917.01	10782.51	1134.50	9.52
Kafr El-Batikh 2	98967.36	89961.33	9006.03	9.10
Kafr El-Maiasra	4531.33	3941.10	590.10	13.00
Dakhala2	36867.60	31806.72	5060.88	13.70
El-Rahamna	17832.67	16159.97	1672.70	9.38

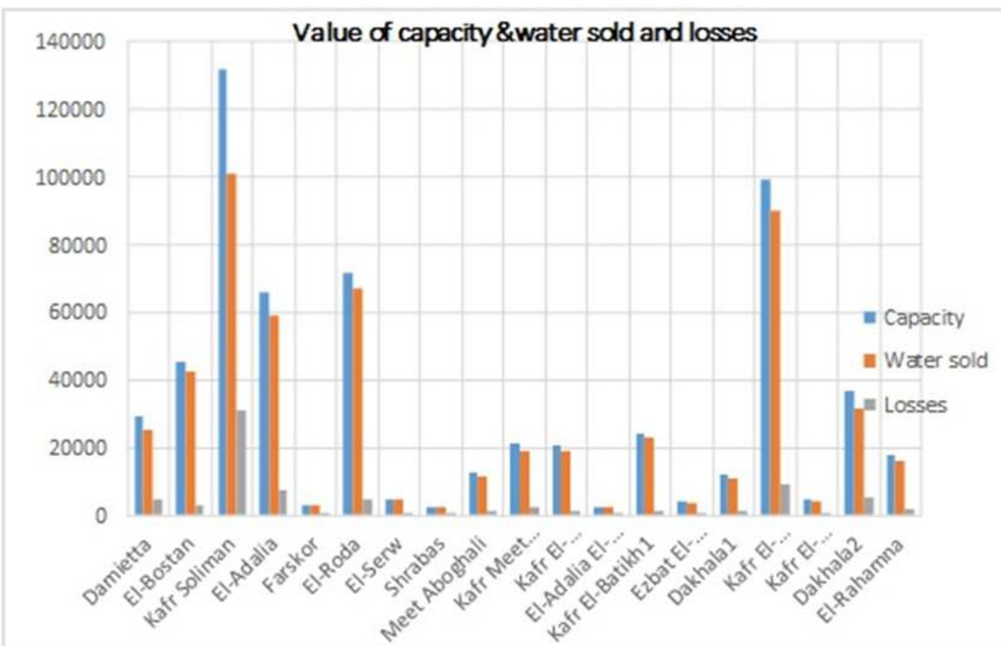

Fig. 1. The relation between capacity, water sold and losses versus water treatment plants in Damietta governorate

Table 2 represent the relation between types of water treatment plants and percentage of losses. The same relation is presented by Fig. 2. The figure shows the relation between types of water treatment plants employed in Damietta governorate on X-axis versus percentage of losses on Y-axis. Damietta governorate employs three types of water treatment plants. The employed technologies are surface water treatment plants, compact water treatment plants, and developed compact water treatment plants with 14, 11.6 and 11.27 percentage of losses, respectively. Surface water treatment plants have the greatest percentage of losses and developed compact water treatment plants has the least percentage of losses. This might be due to the fact that both the compact units and developed compact water treatment plants contains less connections and smaller treatment units volume compared to those of surface water treatment plants. This will results in lower probability to encounter mistakes and lower chance for losses to exist.

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Table 2. The water losses for different types of water treatment plants in Damietta governorate

WTP Type	Percentage of average losses
Surface	14.00%
Compact	11.60%
Developed	11.27%

Tables 3 shows the results of the water losses for the pipe networks that contain PVC water pipes. The table represents the relation between the percentages of unaccounted-for water in a pipe network versus the percentage of PVC pipe lengths to the total lengths of all pipes in the same network. The same relation is presented by Fig. 3. The figure shows the relation between the percentages of PVC pipe lengths to the total

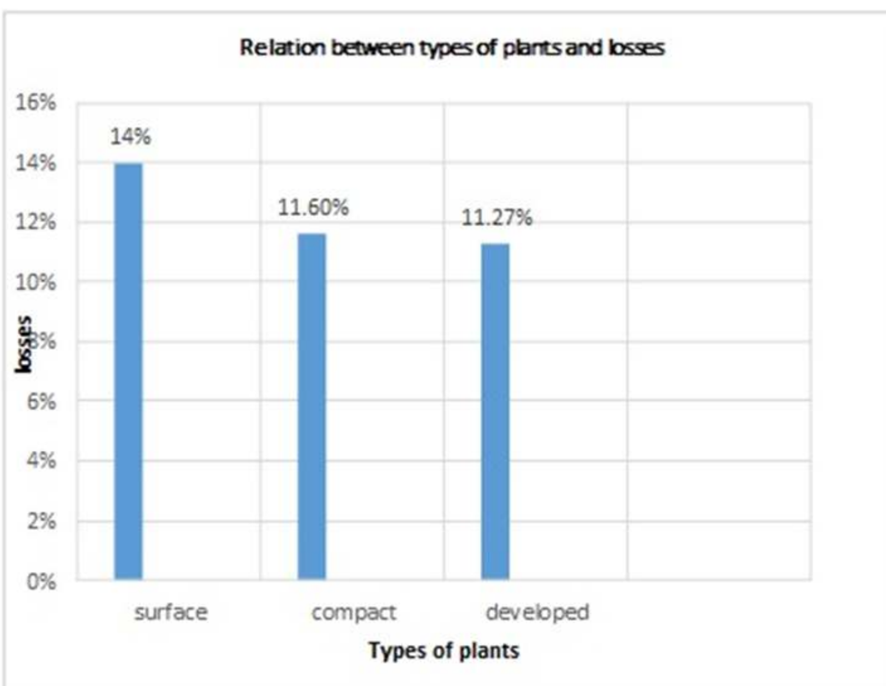

Fig. 2. The water losses for different types of water treatment plants in Damietta governorate

lengths of all pipes in some networks on X-axis versus the percentage of unaccounted-for water in the same pipe networks on Y-axis. Generally, the percentages of unaccounted-for water in pipe networks, that contain PVC pipes, ranged between 4.70 and 23.50% for PVC pipes with percentages ranged between 27.61 and 90.08% by length. These results lie within the accepted range for water losses nominated by the Holding Company. According to Fig. 3, the losses, gradually, decreased by increasing the percentage of PVC pipe lengths in pipe network to the total lengths of all pipes in the same network. The effect of increasing the percentage of PVC pipe lengths in pipe network to the total lengths of all pipes in the same network may be attributable to the fact that increasing percentage of PVC pipe lengths ensures increased impermeability and closes the open pores in the pipes. PVC pipes, also, provides tighter connections due to thermal welding. On the contrary, head and tail connections in cast iron pipes, for example, don't assure the same tightness. These results are considered to be significant enough to accept the PVC pipe material as a leakage reducing type. The relation between the percentages of PVC pipe lengths to the total lengths of all pipes in some networks versus the percentage of unaccounted-for water in the same pipe networks are represented by the following deduced equation;

$$y = 2E\text{-}05x2 - 0.0029x + 0.2156 \qquad (1)$$

Where;

y is the percentages of unaccounted-for water in pipe networks, %
x is the percentage of PVC pipe lengths to the total lengths of all pipes in the same networks, %

The R-squared value of that equation is 0.1402, which is considered to be relatively low and reduce the reliability of the equation. But, this equation can be refined to increase the R-squared value using the results of water losses for more pipe networks, which was not available during this research. To increase the R-squared value, the order of equation might be increased, but this may results in much more complicated formula to be used.

Table 4 shows the results of the water losses for the pipe networks that contain asbestos water pipes. The table represents the relation between the percentages of unaccounted-for water in a pipe network versus the percentage of Asbestos pipe lengths to the total lengths of all pipes in the same network. The same relation is presented by Fig. 4. The figure shows the relation between the percentages of Asbestos pipe lengths to the total lengths of all pipes in some networks on X-axis versus the percentage of unaccounted-for water in the same pipe networks on Y-axis. Generally, the percentages of unaccounted-for water in pipe networks that contain Asbestos pipes, ranged between 6.5 and 11 % for asbestos pipes with percentages ranged between 7.74 and 66.27 % by length. These results lie within the accepted range for water losses nominated by the Holding Company. According to Fig. 4, the losses, gradually, increased by increasing the percentage of asbestos pipe lengths in pipe network to the total lengths of all pipes in the same network. The effect of increasing the percentage of Asbestos pipe lengths in pipe network to the total lengths of all pipes in the same network may be attributable to the rigidity of asbestos pipe connections and poor corrosion resistance to aggressive soil type, such as in Damietta governorate. To avoid such little increased losses with increased asbestos pipe lengths, flexible joints can be used to allow some deflection. These results indicates that PVC pipe material is preferable than asbestos in terms of water losses reduction [12]. The relation between the percentages of asbestos pipe lengths to the total lengths of all pipes in some networks versus the percentage of unaccounted-for water in the same pipe networks are represented by the following deduced equation;

$$y = 1E\text{-}05x^2 + 0.0005x + 0.0738 \qquad (2)$$

Where;

y is the percentages of unaccounted-for water in pipe networks, %
x is the percentage of Asbestos pipe lengths to the total lengths of all pipes in the same networks, The R-squared value of that equation is 0.2111%, which is considered to be relatively low and reduce the reliability of the equation. But, this equation can, also, be refined to increase the R-squared value increasing the order of equation.

Tables 5 shows the results of the water losses for the pipe networks that contain steel water pipes. The table represents the relation between the percentages of unaccounted-for water in a pipe network versus the percentage of steel pipe lengths to the total lengths of all pipes in the same network. The same relation is presented by Fig. 5. The figure shows the relation between the percentage of steel pipe lengths to the total lengths of all pipes in some networks on X-axis versus the percentage of unaccounted-for water in the same pipe networks on Y-axis.

Table 3. The percentage of water losses for the pipe networks that contain PVC water pipes

Net works	Percentage of losses	Percentage of PVC pipes
Damietta	15.00%	27.61%
El-Adalia	11.00%	31.67%
Kafr El-Batikh 2	9.10%	40.78%
Kafr Soliman	23.50%	41.43%
Shrabas	16.00%	42.91%
Dakhala1	9.52%	46.46%
Ezbat El-Nahda	15.00%	48.89%
El-Serw	6.95%	49.92%
El-Bostan	6.00%	51.14%
Kafr El-Batikh1	4.70%	52.2%
El-Adalia El-Modaga	10.20%	58.79%
Kafr El-Shenawi	6.50%	61.13%
El-Rahamna	9.38%	61.32%
Kafr El-Maiasra	13.00%	62.58%
Farskor	10.20%	64.44%
Meet Aboghali	9.52%	69.44%
Dakhala2	13.70%	74.36%
El-Roda	6.50%	90.08%

Generally, the percentages of unaccounted-for water in pipe networks that contain steel pipes, ranged between 4.70 and 23.50% for steel pipes with percentages ranged between 0.13 and 0.91% by length. These results lie within the accepted range for water losses nominated by the Holding Company. According to Fig. 5, the losses, gradually, increased by increasing the percentage of steel pipe lengths in pipe network to the total lengths of all pipes in the same network.

The effect of increasing the percentage of steel pipe lengths in pipe network to the total lengths of all pipes in the same network can't be responsible for that dramatic change in percentages of unaccounted-for water in the same pipe networks, because of the minor percentage of steel pipe lengths in that networks. Also, the fact that steel has high mechanical strength, shock resistance, ability to deflect without breaking, easy of fabrication of large pipes and variety of strengths available [13], implies that increasing the percentage of steel pipe lengths in a network would decrease the losses, under good maintenance conditions. Yet, these results are considered to be acceptable to announce the steel pipe material as a leakage increasing type. The relation between the percentages of steel pipe lengths to the total lengths of all pipes in some networks versus the percentage of unaccounted-for water in the same pipe networks are represented by the following deduced equation;

$$y = 0.0485x2 + 0.0192x + 0.0971 \quad (3)$$

Where;

y is the percentages of unaccounted-for water in pipe networks, %
x is the percentage of steel pipe lengths to the total lengths of all pipes in the same networks, The R-squared value of that equation is 0.1263%, which is considered to be relatively low and reduce the reliability of the equation. But, this equation can be refined to increase the R-squared value using the results of water losses for more pipe networks, which was not available during this research. To increase the R-squared value, the order of equation should be increased.

Table 4. The results of the water losses for the pipe networks that contain Asbestos water pips

Networks	Percentage of losses	Percentage of asbestos pipes
Elroda	6.50%	7.74%
Met abo ghali	9.52%	13.77%
Elrahmna	9.38%	21.14%
Kafer elshnawi	6.50%	23.57%
Dakhala2	13.70%	25.51%
Kafr elmaisra	13.00%	26.53%
kafer elbatikh1	4.70%	31.06%
Kafr met aboghali	10.20%	31.16%
Shrbas	16.00%	36.55%
Farskor	10.20%	37.75%
Elbostan	6.00%	39.38%
Elsrw	6.95%	40.90%
kafer elbatikh2	9.10%	46.61%
Ezbat elnahda	15.00%	47.68%
Dakhala1	9.52%	48.19%
Kafr sleman	23.50%	56.71%
Damietta	15.00%	65.38%
Eladalia	11.00%	66.27%

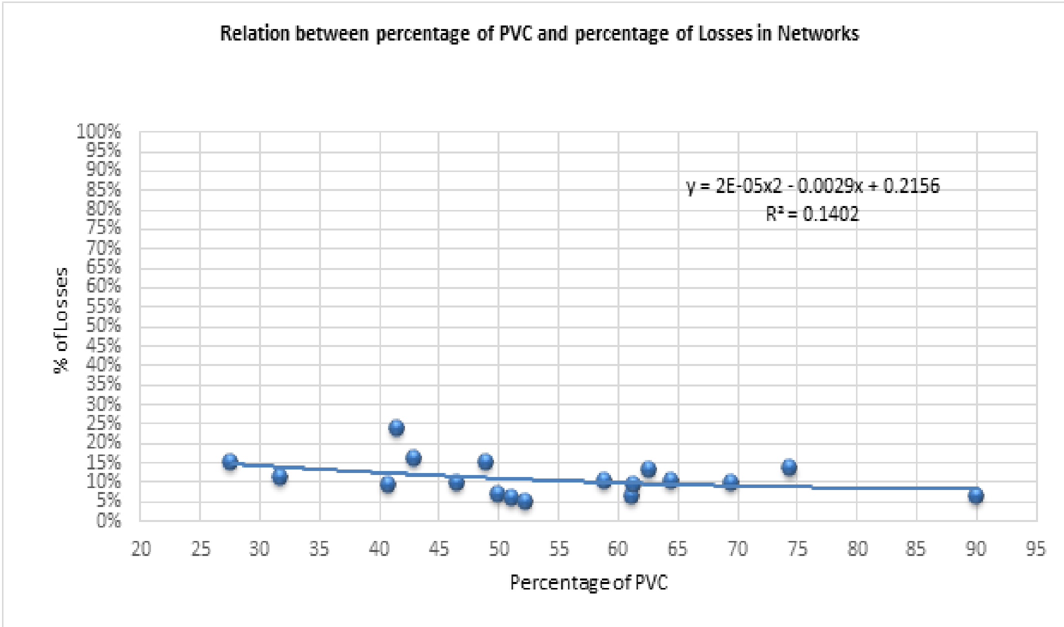

Fig. 3. The relation between the percentages of PVC pipe lengths to the total lengths of all pipes in some networks versus the percentage of unaccounted-for water in the same pipe networks

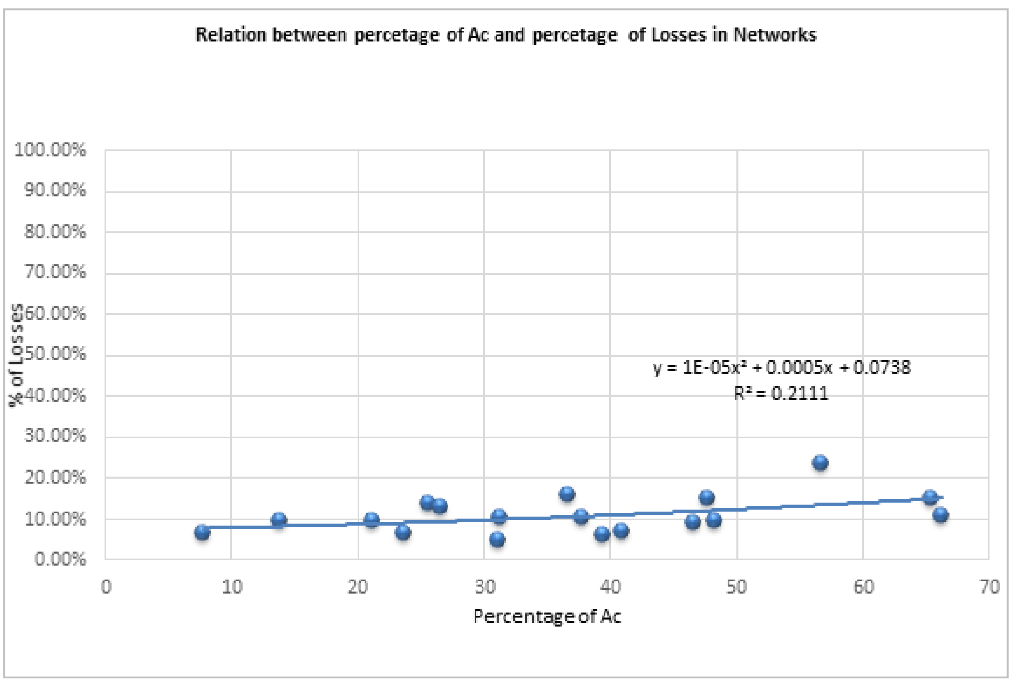

Fig. 4. The relation between the percentages of asbestos pipe lengths to the total lengths of all pipes in some networks versus the percentage of unaccounted-for water in the same pipe networks

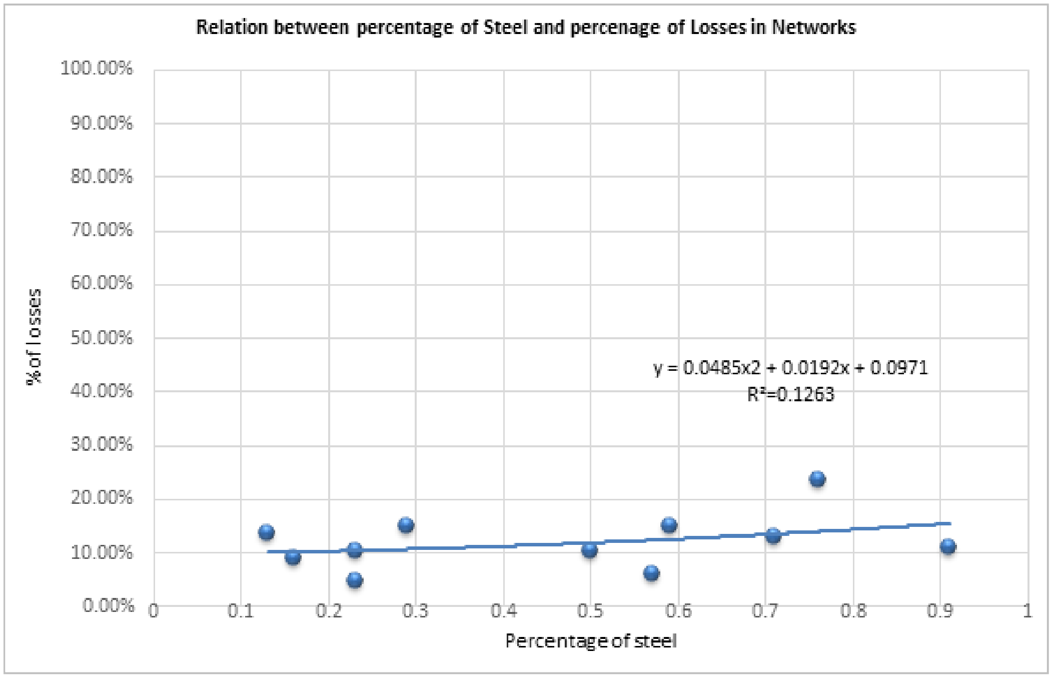

Fig. 5. The relation between the percentages of Steel pipe lengths to the total lengths of all pipes in some networks versus the percentage of unaccounted-for water in the same pipe networks

Table 5. The results of the water losses for the pipe networks that contain steel water pipes

Networks	Percentage of losses	Percentage of steel
Dakhala2	13.70%	0.13%
Kafr El-Batikh 2	9.1%	0.16%
Kafr El-Batikh 1	4.70%	0.23%
Kafr Meet Aboghali	10.20%	0.23%
Ezbat El-Nahda	15%	0.29%
Farskor	10.20%	0.50%
El-Bostan	6.00%	0.57%
Damietta	15.00%	0.59%
Kafr El-Maiasra	13.00%	0.71%
Kafr Soliman	23.5%	0.76%
El-Adalia	11.00%	0.91%

Tables 6 shows the results of the water losses for the pipe networks that contain cast iron water pipes. The table represents the relation between the percentages of unaccounted-for water in a pipe network versus the percentage of cast iron pipe lengths to the total lengths of all pipes in the same network. The same relation is presented by Fig. 6. The figure shows the relation between the percentage of cast-iron pipe lengths to the total lengths of all pipes in some networks on X-axis versus the percentage of unaccounted-for water in the same pipe networks on Y-axis. Generally, the percentages of unaccounted-for water in pipe networks, that contain cast iron pipes, ranged between 4.70 and 23.50% for cast iron pipes with percentages ranged between 0.23 and 17.54% by length. These results lie within the accepted range for water losses nominated by the Holding Company. According to Fig. 6, the losses, gradually, decreased by increasing the percentage of cast iron pipe lengths in pipe network to the total lengths of all pipes in the same network.

The effect of increasing the percentage of cast iron pipe lengths in pipe network to the total lengths of all pipes in the same network may be attributable to the fact that increasing percentage of cast iron pipe lengths ensures increased impermeability due to the low permeability of this pipe material. These results are considered to be significant enough to accept the cast iron pipe material as a leakage reducing type, [12]. The relation between the percentages of cast iron pipe lengths to the total lengths of all pipes in some networks versus the percentage of unaccounted-for water in the same pipe networks are represented by the following deduced equation;

$$y = 0.0031x2 - 0.0474x + 0.2061 \quad (4)$$

Where;

y is the percentages of unaccounted-for water in pipe networks, %
x is the percentage of cast iron pipe lengths to the total lengths of all pipes in the same networks, The R-squared value of that equation is 0.169%, which is considered to be relatively high and increase the reliability of the equation.

Tables 7 shows the results of the water losses for the pipe networks that contain GRP water pipes. The table represents the relation between the percentages of unaccounted-for water in a pipe network versus the percentage of GRP pipe lengths to the total lengths of all pipes in the same network.

The same relation is presented by Fig. 7. The figure shows the relation between the percentage of GRP pipe lengths to the total lengths of all pipes in some networks on X-axis versus the percentage of unaccounted-for water in the same pipe networks on Y-axis. Generally, the percentages of unaccounted-for water in pipe networks, that contain GRP pipes, ranged between 4.70 and 23.50% for GRP pipes with percentages ranged between 0.28 and 2.45% by length. These results lie within the accepted range for water losses nominated by the Holding Company. According to Fig. 7 above, the losses, gradually, decreased by increasing the percentage of GRP pipe lengths in pipe network to the total lengths of all pipes in the same network.

Table 6. The results of the water losses for the pipe networks that contain Cast-iron water pipes

Networks	Percentage of losses	Percentage of cast-iron
Kafr Meet Aboghali	10.20%	0.23%
Farskor	10.20%	0.50%
Kafr Soliman	23.50%	0.82%
El-Adalia	11.00%	1.14%
El-Roda	6.50%	2.18%
Ezbat El-Nahda	15.00%	2.84%
Dakhala1	9.52%	4.22%
El-Bostan	6.00%	5.33%
Damietta	15.00%	6.33%
El-Serw	6.95%	9.18%
Kafr El-Maiasra	13.00%	10.18%
Kafr El-Batikh1	4.70%	10.55%
Kafr El-Shenawi	6.50%	15.30%
Meet Aboghali	9.52%	16.79%
El-Rahamna	9.38%	17.54%

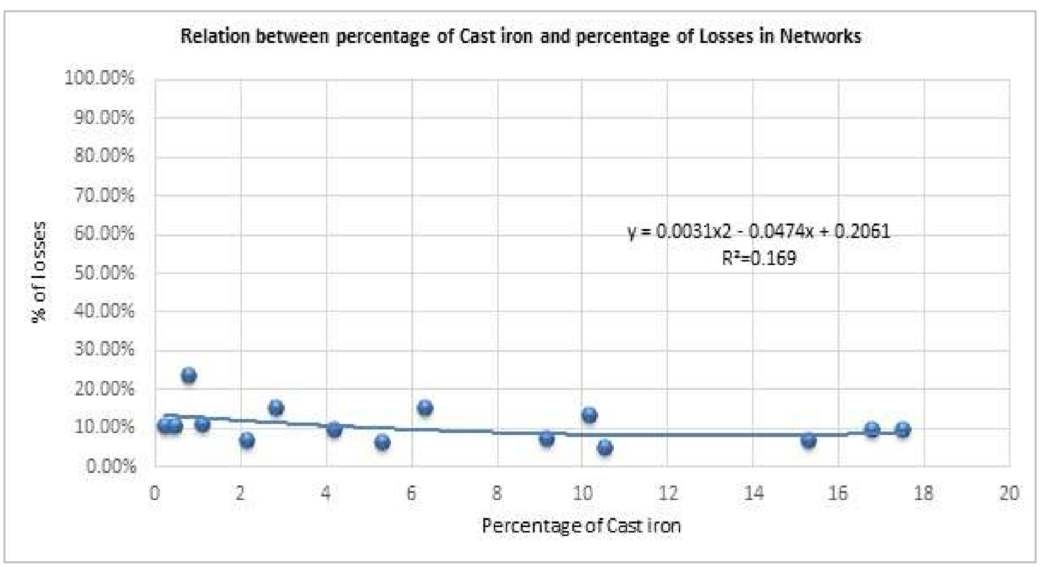

Fig. 6. The relation between the percentages of cast-iron pipe lengths to the total lengths of all pipes in some networks versus the percentage of unaccounted-for water in the same pipe networks

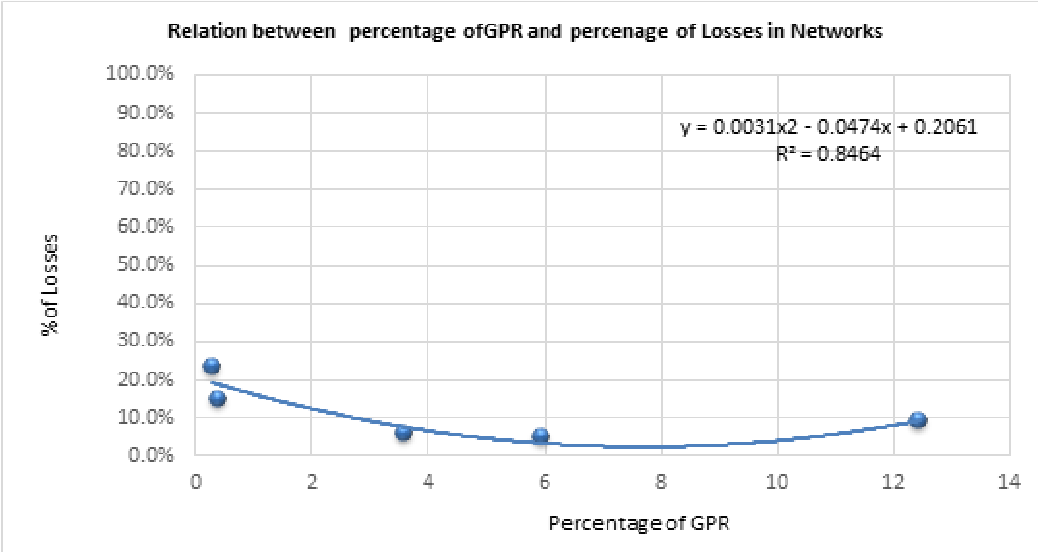

Fig. 7. The relation between the percentages of GRP pipe lengths to the total lengths of all pipes in some networks versus the percentage of unaccounted-for water in the same pipe networks

Table 7. The results of the water losses for the pipe networks that contain GRP water pipes

Networks	Percentage of losses	Percentage of GBR
Kafr Soliman	23.50%	0.28%
Damietta	15.00%	0.39%
El-Bostan	6.00%	3.58%
Kafr El-Batikh 1	4.70%	5.96%
Kafr El-Batikh 2	9.10%	12.45%

The effect of increasing the percentage of GRP pipe lengths in pipe network to the total lengths of all pipes in the same network may be attributable to the fact that increasing percentage of GRP pipe lengths ensures increased toughness and tight thermal welded connections in the pipes, [14,15]. These results, significantly, imply considering the GRP pipe material as a leakage reducing type. The relation between the percentages of GRP pipe lengths to the total lengths of all pipes in some networks versus the percentage of unaccounted-for water in the same pipe networks are represented by the following deduced equation;

$$y = 0.0031x2 - 0.0474x + 0.2061 \qquad (5)$$

Where;

Y is the percentages of unaccounted-for water in pipe networks, %

X is the percentage of GRP pipe lengths to the total lengths of all pipes in the same networks, The R-squared value of that equation is 0.8464%, which is considered to be relatively high and increase the reliability of the equation.

4. CONCLUSION

Based on studying types of water treatment plants, capacity, water sold, losses for each water treatment plants and for networks losses, types of pipes, the following conclusion were drawn;

- The percentage of average losses in developed water treatment plants was 11.27%, which is the least percentage of average losses in all the water treatment plants employed throughout Damietta governorate. Developed compact water treatment plants might be preferable in terms of losses reduction, unless it conflicts with achieving the different design aims.
- The percentage of average losses in surface water treatment plants was 14%, which is the greatest percentage of average losses in Damietta all the water treatment plants employed throughout Damietta governorate. Surface water treatment plants are not preferable in terms of losses reduction, unless

they are needed to achieve other design aims.

- The percentage of losses decrease with increasing the percentage of PVC pipe lengths to the total lengths of all pipes, but there are some cases in which the percentage of losses increased in the presence of high percentage of PVC pipes. This might be attributed to construction defects and poor joint welding not as much to the PVC material.
- The percentage of losses increase with increasing the percentage of asbestos pipe lengths to the total lengths of all pipes. This might be attributable to the rigidity of asbestos pipe connections and poor corrosion resistance to aggressive soil type, such as in Damietta governorate.
- The percentage of losses increase with increasing the percentage of steel pipe lengths to the total lengths of all pipes. This might be attributed to the corrosion of steel pipes due to aggressive nature of soil and poor maintenance conditions.
- The percentage of losses decrease with increasing the percentage of cast iron pipe lengths to the total lengths of all pipes. This might be attributable to the fact that increasing percentage of cast iron pipe lengths ensures increased impermeability due to the low permeability of this pipe material. But there are some cases of in which the percentage of losses increased in the presence of high percentage of cast iron pipes. This might be attributed to construction defects, poor maintenance conditions, and poor joint welding not as much to the cast iron material.
- The percentage of losses decrease with increasing the percentage of GRP pipe lengths to the total lengths of all pipes, but there are some rare cases of in which the percentage of losses increased in the presence of high percentage of GRP pipes. This might be attributed to construction defects and poor joint welding.
- Expanding the use of developed compact water treatment plants might reduce the percentage of losses, regardless the other design aspects.
- To reduce the percentage of losses in networks it is recommended to rely heavily on PVC, cast iron and GRP pipes compared to other pipe materials.
- Reduction of asbestos and steel pipes use to a minimum in networks will decrease losses as the losses heavily increases with increasing lengths of these pipes in networks.

5. RECOMMENDATIONS FOR FURTHER RESEARCH

The work of the present study was mainly concerned with investigating the possibility of reducing the losses in water treatment plants and networks in Damietta governorate by recognizing the actual governing reasons for it. The results implied the following recommendations;

- The effect of pipe size and material on water losses in networks should be studied for other networks at different governments in Egypt.
- Further research needed to be directed to the effect of pipe size on other pipe materials available in Egyptian market such as prestressed concrete.
- Further intention should be given to other causes of losses in pipe networks in Egypt, such as pipe age, pipe internal surface conditions, and soil type.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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