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Effect of the permanent presence of major agricultural drains on the Nile River water quality

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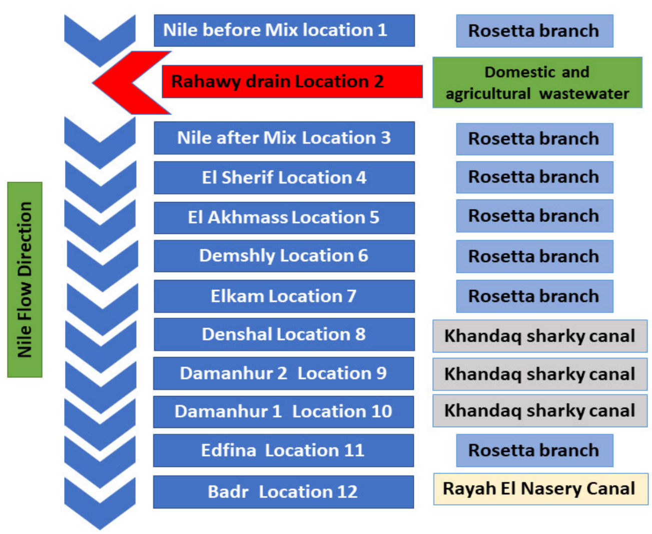
A B S T R A C T

This work was designed to study the effect of major drains, such as El Rahawy, on the Nile's water quality over time. The data in this study includes six years of physical and chemical variables data, starting from 2015 to 2020, covering three different water streams. The present results showed that the Rosetta branch and Khandaq sharky canal were directly affected by the agricultural drainage of the Rahway drain, with the change over time for the worse. Rayah El Nasery canal enjoyed complete independence from the negative impact of the drain while maintaining the quality at an appropriate level over time. The study predicts a decline in the water quality of the Rosetta branch in the future and recommends exerting more efforts to treat all pollutants that are discharged on the Nile and raise the efficiency of the Rahawy drain.



Graphical Abstract

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1. Introduction

The Nile is Egypt's major source of fresh water, yet it is also affected by human influences and uncontrolled agricultural pollution. The eastern branch, with a length of around 229 km, is the Damietta branch. The Nile Delta's western side receives the majority of its water from the western Rosetta branch, which runs for 220 kilometers to the northwest down the delta barrage. Due to the discharge of various flows, including residential, industrial, and agricultural waste, the two branches' water quality values are greater than those of the Nile.[1] The primary contributors to the Rosetta branch are industrial effluents, sewage points, and farmland. Out of 67 drains from Aswan to the barrages of the Delta, only 10 agricultural drains out of 43 central farming drains follow the Egyptian law for dumping agricultural effluent into the river.[2]

One of the main drains at the Rosetta branch, the Rahawy drain in the Delta area, receives a significant amount of wastewater from the Greater Cairo area. The Rosetta branch receives around 2 million m^3/day of drainage water from the Rahawy drain, which has a considerable influence on the branch's water quality.[3] The water quality of the El Rahway drain may be impacted and degraded by two important sources of pollution: first, wastewater treatment facilities, notably Abu Rawash and Zenein, have a big impact on the river's water quality. Second, without any filtering, farming and household garbage from villages dispersed along the drain release their waste directly into water canals.[4]

Previous studies showed that the twelve sites depended on studying the water quality change over locations. The Rahawy drain had a significant negative impact on the water quality in the following drain locations.[4] Therefore, in our current study, we tried to discover the amount of change over time on all twelve sites.

The current study aims to: (1) evaluate the water quality of the three water paths, (2) assess the water quality of every location during the time change, and (3) Examine the Rahawy drain impact on every location over time change.

2. Material and methods

2.1. Research methodology

The research approach is represented in (**Fig. 1**); The research began by establishing a sampling strategy and locations where samples will be collected from 2015 to 2020. In situ measurements and laboratory testing assess the research area's water quality characteristics. Spatial distribution of the water quality parameters is obtained. Studying the water quality changes over time. Finally, Investigate the factors that influence the quality of the research area and how to mitigate these factors.

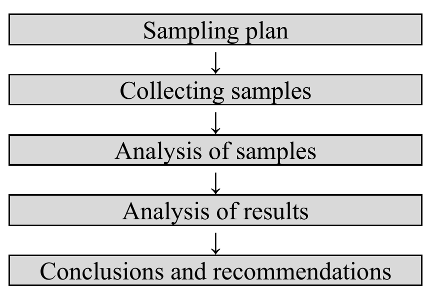

Fig. 1. Research methodology of the study article.

2.2. Study area

Starting from the north of Cairo governorate, we start the sampling from the Rosetta branch, one of the main branches of the Nile River, which is approximately 220 km long. The sampling strategy aims to check the Nile before and after the pollution point, among which the most critical source is the Rahawy drain. The Rahawy drain discharges 400,000 m^3/day of sewage and domestic and agricultural waste.[4] Starting from the Nile River (L1), Rahawy drain (L2), and proceeding through Menofia and Gharbia Governorate with locations (L3, L4, L5, L6, L7) reaching Edfina city (L11), which is related to the first study path. From northern Cairo L1 to reach L12, is the second path. The third path, related to Khandaq sharky canal, contains three locations L8, L9, and L10 as shown in (**Fig. 2**).

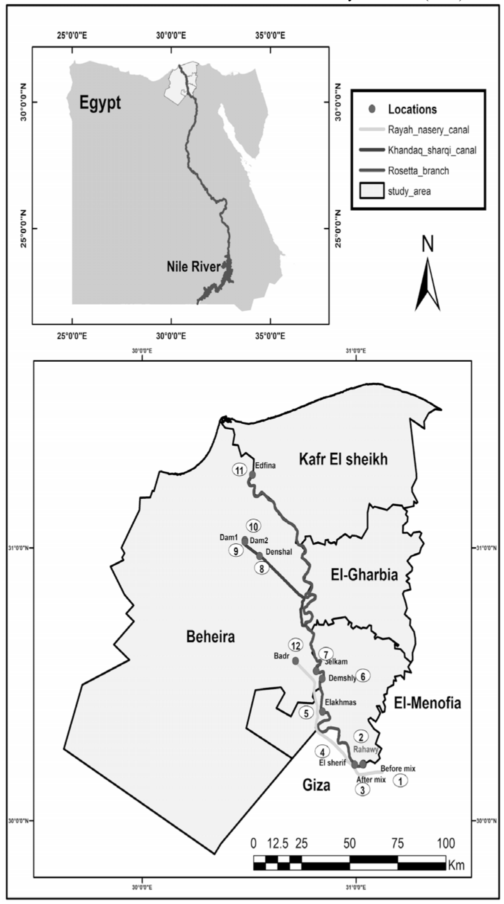

Fig. 2. The study locations of twelve sites in the northern of Egypt.[4]

2.3. Sampling program

The sampling procedure was guided by technical guidelines for controlling surface water and wastewater for six years along the research area. Just below the water's surface, water samples were collected using the standard APHA 23rd edition water and waste assessment methodology. Each sampling site provided water samples, which were taken and subjected to physical and chemical examinations. Depending on the variables that needed to be examined, water samples were taken from each location in various containers.

2.4. Analytical procedures

The study was carried out by selecting twelve physicochemical variables. The variables that used in this study are as follows: pH meter (Thermo), Total suspended solids (TDS) (Thermo), Turbidity (Hach), Total hardness (Titration), Chloride (Titration), The heavy metal (Fe, Mn, Cu) is detected using (Thermo ICE 3500 atomic absorption spectrometer) and (Nitrate, Nitrite, Phosphate, Sulphate) were detected using (Dionex-600 ion chromatography). All the records were compared to the Egyptian standard for the drinking water limits **Table (1)**.

Table 1. Water Quality Variables limits according to ESDWL.[5]

No	Parameter	ESDWL Guidelines
1.	pH	6.5-8.5
2.	TDS mg/L	1000
3.	Fe mg/L	0.3
4.	Mn mg/L	0.4
5.	Cu mg/L	2
6.	NO_3^- mg/L	45
7.	SO_4^{-2} mg/L	250
8.	NO_2^- mg/L	0.2
9.	Turbidity NTU	1
10.	Total hardness	500
11.	Cl^-	250
12.	Na^+ mg/L	200

3. Results and discussion

3.1. *Physical and chemical parameters change over time in the north of Egypt*

3.1.1. Water quality changes for the Nile before mixing location (L1).

Fig. 3 represents the pH, nitrate, and turbidity parameters measured in location 1 between 2015 and 2020. The pH variable showed no significant change during the six years of study and was within the permissible limit during the study period, where the turbidity parameter shows a slight change as the year 2020 recorded the highest record by 9.0 NTU and the lowest value recorded in 2015 by 5.0 NTU. The nitrate level in location no.1 slightly changed between the years and was below the permissible limit all the study time.

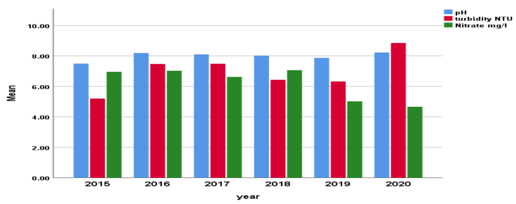

Fig. 3. Turbidity, nitrate, and pH variables overtime in location no.1.

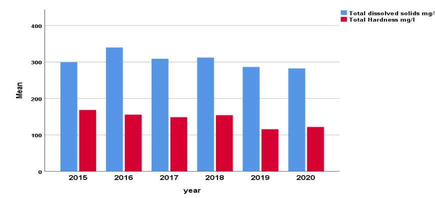

Fig. 4. Total dissolved solids and total hardness variables overtime for the Nile before mix location (L1).

The TDS values were recorded in location one within the permissible limit for drinking water, showing no significant variation between the years. The total hardness parameter shows a decreasing trend from 2015 to 2020, where the highest value recorded in 2015 and 2020 was the lowest value recorded, as shown in (**Fig. 4**).

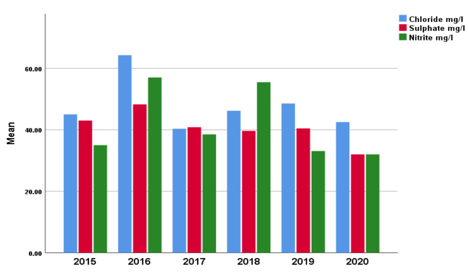

Fig. 5. Chloride, sulphate, and nitrite variables overtime for the Nile before mix location.

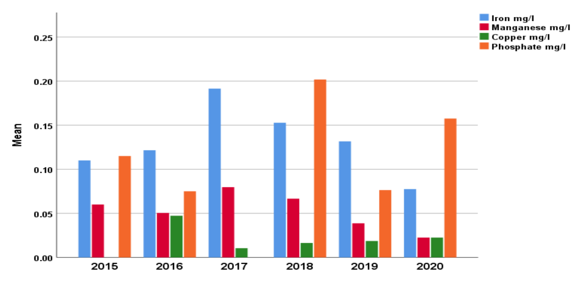

Fig. 6. Iron, Copper, manganese, and phosphate variables overtime for the Nile before mix location.

Chloride level measured in location one shows a significant variation between the years, where the highest value was recorded at more than 60.0 mg\L in 2016, and the lowest was 40.0 in 2017. The sulphate level shows no significant variation between the years, as shown in (**Fig. 5**). Chloride and sulphate level in location one was below the drinking water permissible limits. The measured nitrite level shows significant variation between the years, where the highest values were detected below 60.0 mg\L in 2016 and 2019. All the nitrite concentration in location one measured in the study period was above the drinking water limit (0.2 mg\L). **Fig. 6** represents the heavy metals measured in location one, where Fe, Mn, and Cu were below the permissible limits for drinking water. The Fe level shows significant variation between the years, as the highest value was measured at 0.18 and 0.15 mg\L in 2016 and 2017, respectively. The phosphate level showed low concentrations and a significant variation, where the maximum level recorded in 2018 was 0.20 mg\L and was below the detection limit in 2017.

3.1.2. Water quality change for the Rahawy drain (L2).

Fig. 7 and **Fig. 8** represent the physical variables measured for location 2 between 2015 and 2020. The pH variable shows no change during the five years of study, where the mean turbidity shows a slight change as the years 2019 and 2020 recorded the highest record over 60 NTU and the lowest value recorded in 2015 by 55 NTU. The change in the TDS shows an increase in the last three years as the recorded value was more than 900 mg\L. The total hardness shows a slight change during the six years of study, with the same mean value recorded for 2015, 2016, and 2018 and slightly decreased in 2020 lower than 200 mg\L.

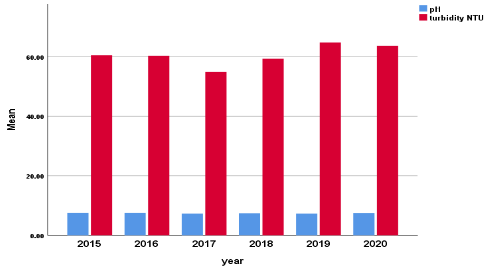

Fig. 7. pH and turbidity variables at the Rahawy drain over six years trend.

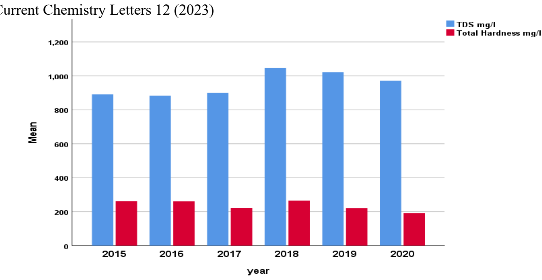

Fig. 8. TDS and total hardness variables at the Rahawy drain over six years trend.

The mean chloride value shows an increase in the last four years as the recorded value was more than 200 mg\L, while the mean nitrite values were higher in 2018 and 2019 than in the other years. The sulphate variable slightly changed over the six years, and 2017 recorded the highest value of more than 150 mg\L (**Fig. 9**). **Fig. 10** shows the heavy metals during the six years of study in the Rahawy drain. The mean iron concentrations were above the permissible limits in the six years, with a significant increase in 2017, 2018, and 2020, especially in 2017, as the recorded value exceeded 1.0 mg\L. The Cu and Mn show no significant change during the six years. The phosphate level was greater than location no.1, with a significant variation between the years, where the highest value was more than 3.0 mg\L recorded in 2017, and the lowest value was 1.8 mg\L in 2018.

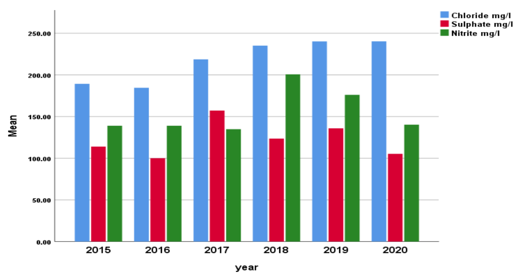

Fig. 9. Chloride, sulphate, and Nitrite variables at the Rahawy drain over six years.

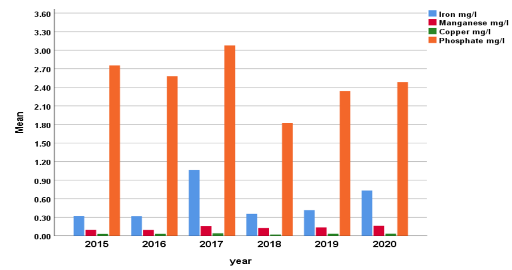

Fig. 10. Fe, Cu, Mn, and PO_4^{-2} over six years of measurements at the Rahawy drain.

Fig. 11. represents the nitrate trend during 2015 – 2020 at the Rahawy drain, as a significant increase shows in the year 2020, as the nitrate levels recorded the highest value in the six years by nitrate mean value of more than 100 mg\L, while other years, the nitrate mean values were below the 20 mg\L.

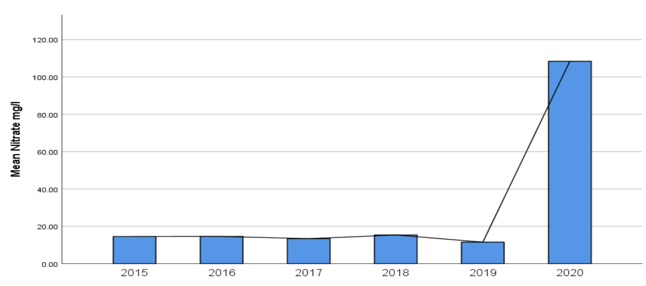

Fig. 11. The trend of nitrate concentration at the Rahawy drain over six years.

3.1.3. Water quality changes after mixing location (L3).

Fig. 12 and **Fig. 13** represent the physical variables in location 3 during the study period 2015- 2020. The pH variable shows no change during the six years, while the turbidity shows significant variation. The year 2015 recorded the highest mean value for the turbidity as it almost reached 50 NTU, then a significant drop happened in 2016 as the turbidity was below 20 NTU, then the following year started to increase dramatically till reaching more than 30 NTU. The total hardness variable shows slight variation through the six years, while the TDS variable has the same sequence of turbidity as 2015 recorded the highest level of TDS, which was below 1000 mg\L then by the year 2017, it reached the smallest value during the six years was below 500 mg\L.

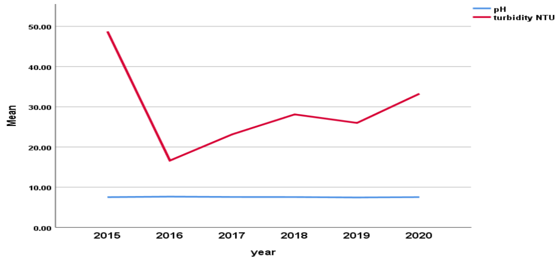

Fig. 12. pH and turbidity water quality variables change over six years in L3.

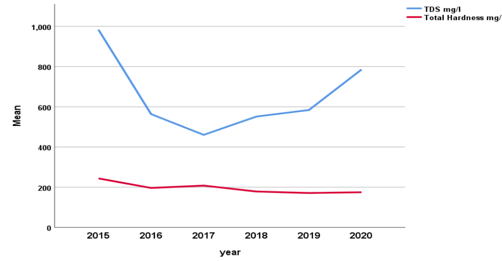

Fig. 13. TDS and total hardness variables change over six years in L3.

Nitrite level over the six-year study shows a slight change where 2015, 2019, and 2020 get the highest nitrite level over 100 mg\L, while 2016, 2017, and 2018 remained without significant change. The sulphate concentrations get the same nitrite trend as the highest levels of sulphate recorded in 2015, 2019, and 2020. Moreover, 2016, 2017, and 2018 sulphate levels show no significant change. The chloride level shows significant change, as the chloride concentrations started in 2015 below 150 mg\L then by 2016, the chloride level dropped dramatically below 100 mg\L then started to increase in 2017 continuously until reaching 2020 with chloride concentration below 200 mg\L (**Fig. 14**).

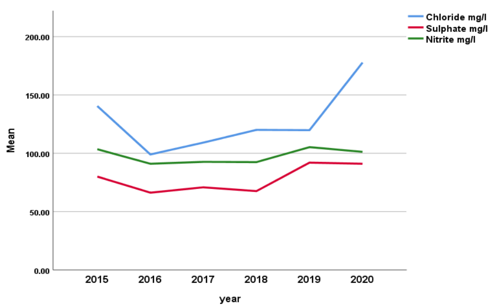

Fig. 14. Cl^-, SO_4^{-2}, and NO_2^- water quality variables change over six years in L3.

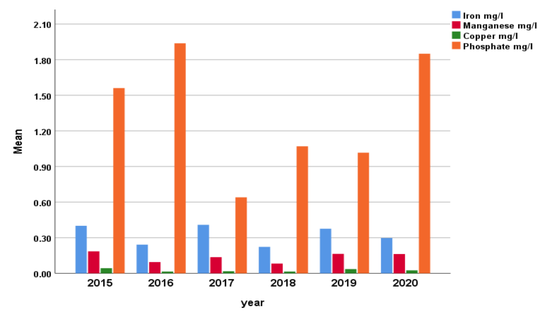

Fig. 15. Fe, Mn, Cu, and PO_4^{-2} water quality variables change over six years in L3.

Fig. 15 represents the heavy metal concentration in location three during the study period. The mean concentration of Fe significantly changes, where 2015, 2017, and 2019 get the highest iron level over 0.3 mg\L. The years 2016 and 2018 get the lowest level below 0.3 mg\L, and in 2020, the iron concentration is on the borderline (0.3 mg\L). Mn and Cu levels showed no significant changes during the study period, and the concentrations were below the permissible limits. Phosphate concentration in location no.3 was lower than in location no.2 with a significant variation, where the lowest value was recorded in 2017, 0.60 mg\L, and the highest values were recorded in 2016 and 2020, 1.80 mg\L (**Fig. 15**). **Fig. 16** shows the nitrate levels, where 2015 and 2017 were above 10.0 mg\L. The lowest nitrate level was recorded in 2020 and was below 8.0 mg\L.

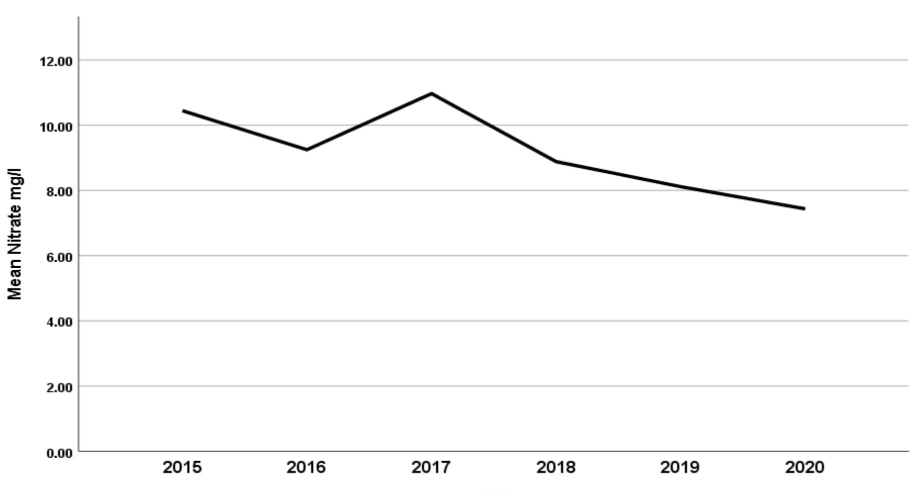

Fig. 16. The nitrate water quality variable changes over six years in L3.

3.1.4. *Water quality change in El sheriff location (L4)*

Fig. 17 and **Fig. 18** represent the pH, turbidity, TDS, and total hardness water quality variables in location (L4). The pH variable is stable and shows no change during the six years. In contrast, the turbidity variable shows significant change during the study period, where 2015, 2016, 2018, 2019, and 2020 showed turbidity of more than 20 NTU exceeded the permissible limits of drinking water. The minimum value recorded was in 2017, as the turbidity was slightly more than 10 NTU.

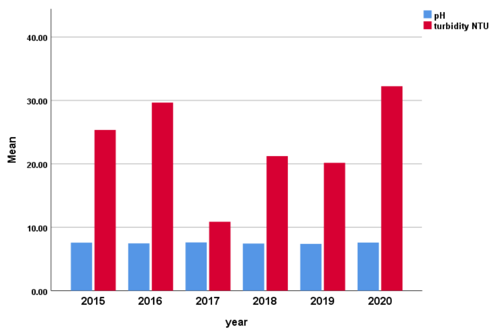

Fig. 17. pH and turbidity variables in location 4 over six years study period.

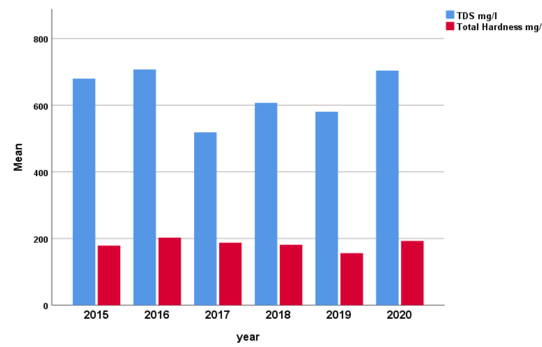

Fig. 18. TDS and total hardness variables in location 4 for six years period.

The total hardness variable shows no significant change during the six years. The TDS variable during 2015, 2016, 2018, 2019, and 2020 was around ± 600 mg\L. In 2017, the TDS was the lowest value recorded in the study period, around 500 mg\L (**Fig. 18**). (**Fig. 19**) The Cl^-, SO_4^{-2}, and NO_2^- variables are represented in Location four. The chloride variable showed a slight change during the study time, and all the results were below the permissible limits of the drinking water. The sulphate variable results were below the permissible limits for all six years, with no significant change. The nitrite variable results were above the permissible limit of the drinking water (0.20 mg\L); all the results show a slight change among the six-year and all below 100 mg\L.

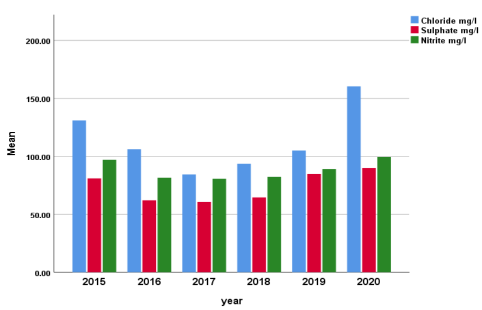

Fig. 19. Chloride, Sulphate, and nitrite variables detected in location 4 for six years.

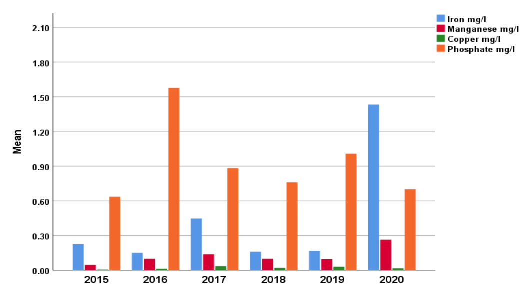

Fig. 20. Fe, Mn, Cu, and PO_4^{-2} variables were measured in location 4 over six years.

Fig. 20 represents the heavy metals concentrations in L4; the iron concentration exceeded the permissible limits (0.3 mg\L) in 2017 and 2020, where the highest concentration being in 2020 (more than 1.40 mg\L). Mn and Cu were below the permissible limits during the whole study period. The phosphate concentration measured showed a significant variation similar to location no.3, where the highest value was recorded at 1.50 mg\L in 2016, and the lowest value was 0.60 mg\L in 2015. During the six-year study period, the nitrate variable concentrations were below the permissible limits (45 mg\L), with no significant change (**Fig. 21**).

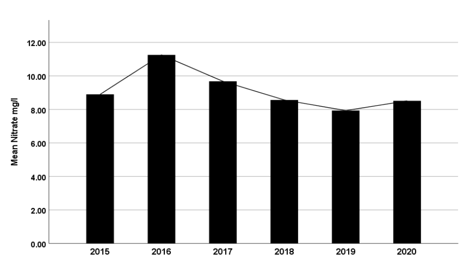

Fig. 21. Nitrate concentrations in location 4 during six years period.

3.1.5. Water quality change in El Akhmas location (L5).

The pH and turbidity variables measured in location 5, shown in (**Fig. 22**), the pH variable shows no change during the six years. The turbidity mean concentration shows significant change during the study period; first, the turbidity was above the permissible limits for all the years; secondly, 2015, 2016, 2019, and 2020 got the highest turbidity value above 20.0 NTU; thirdly, 2017 and 2018 got the lowest turbidity values lower than 10.0 NTU. Finally, the highest value for turbidity among the six years was in 2015, which was above 30.0 NTU.

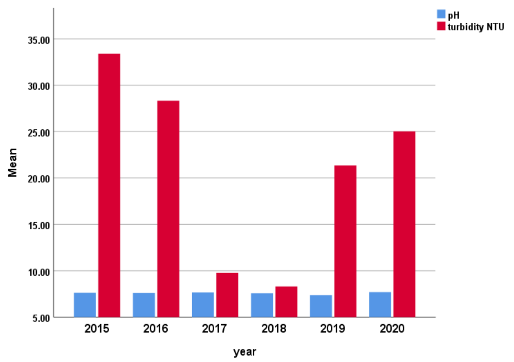

Fig. 22. pH and turbidity variables in location 5 for six years.

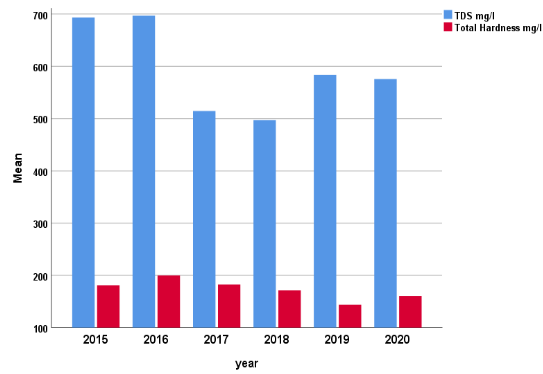

Fig. 23. TDS and total hardness variables in location 5 for six years.

Fig. 23 represents TDS and total hardness variables in location 5 for six years; the total hardness variable in location 5 shows a slight change, and all results are below 200.0 mg\L. The TDS variable shows significant change as the years 2017 and 2018 were around 500.0 mg\L, the highest TDS values were recorded in 2015 and 2016 as they were below 700.0 mg\L, and in 2019, 2020 were below 600.0 mg\L. The chloride variable shows a significant change (**Fig. 24**), as the highest chloride value recorded was above 130.0 mg\L in 2015, and the lowest recorded value was below 80.0 mg\L. All the chloride values were below the permissible limit of drinking water (250 mg\L). Nitrite variable results were above the permissible limits among all years studied. There was a slight change in nitrite values as the minimum values recorded in 2017, 2018, and 2019 were below 80.0 mg\L: and above 80.0 mg\L in 2015, 2016, and 2020. For the sulphate variable, all the years show a slight change around ± 60.0 mg\L, except in 2019, the sulphate concentration was above 80.0 mg\L.

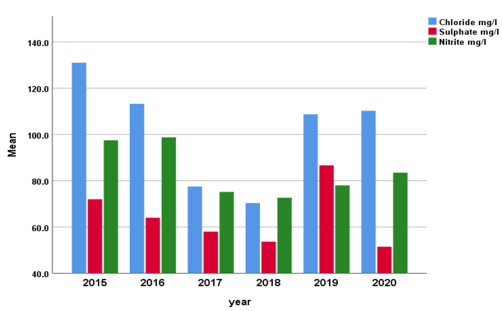

Fig. 24. Cl^-, SO_4^{-2}, and NO_2^- variables in location 5 for six years.

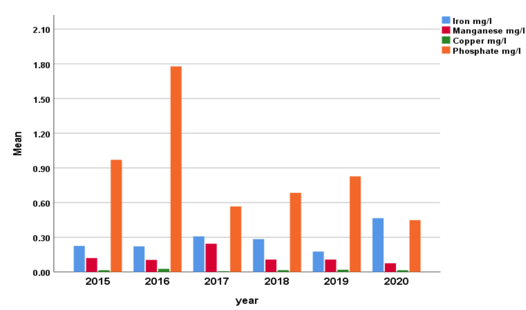

Fig. 25. Fe, Mn, Cu, and PO_4^{-2} variables were measured in location 5 over six years.

The iron concentration in location five is represented in (**Fig. 25**); the iron values are below permissible limits except in 2017 and 2020, where it was above the permissible limits (0.30 mg\L) as the highest value was (above 0.45 mg\L) recorded in 2020. The copper and manganese variables were below the permissible limits, with no significant change during the six years. The significant variation in the high level of phosphate concentration is represented in location five, where the highest value was recorded (about 1.80 mg\L) in 2016, and the lowest value was 0.45 mg\L in 2020 (**Fig. 25**).

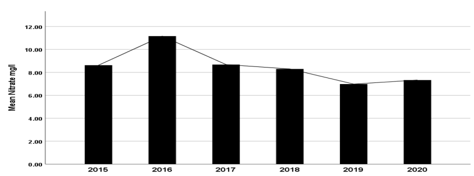

Fig. 26. Nitrate water quality variable in location 5 for six years.

The nitrate concentration slightly changed below the permissible limits (45.0 mg\L) during the whole study period, especially in 2016 (**Fig. 26**).

3.1.6. Water quality change in Demshly location (L6).

The pH, turbidity, TDS, and total hardness water quality variables analyzed in Demshly location (L6) were represented in (**Fig. 27** and **Fig. 28**). The pH variable shows no significant change during the study period from 2015 to 2020. The turbidity level significantly changed during the study period, especially in 2015 and 2020, as the turbidity was above 12 NTU and the highest value. Per contra, the turbidity was slightly changed from 2016 to 2019 as it was recorded below 6.0 NTU in 2016.

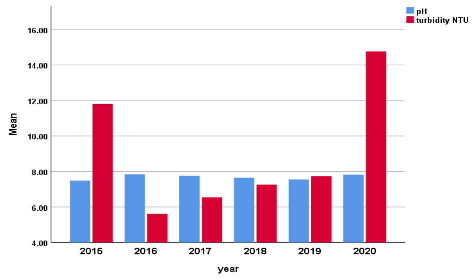

Fig. 27. pH and turbidity variables in location 6 (Demshly).

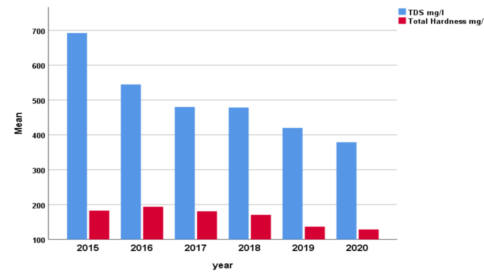

Fig. 28. TDS and total hardness variables in location 6 (Demshly).

The TDS shows a decreasing trend, as the TDS levels started in 2015 below 700 mg\L, then the trend tends to decrease every year until 2020, recording TDS below 400 mg\L. The total hardness levels were in the same trend as the TDS, where the total hardness started in a high concentration below 200 mg\L and then decreased every year until it reached 2020, as the total hardness values were the lowest among the trend (**Fig. 28**). The chloride and sulphate levels were below the permissible limits during the study period, as represented in (**Fig. 29**). The chloride concentration shows a decreasing trend, as 2015 recorded the highest value for chloride at 120 mg\L, then the chloride concentration decreased to reach 2020 and was slightly above 60 mg\L. The sulphate concentration showed a significant change between the years. In 2015, the highest sulphate value was above 80 mg\L, and in 2020 was 40 mg\L. The nitrite variable shows a decreasing trend similar to the chloride trend, where it started in 2015 with the highest value for nitrite above 100 mg\L and then decreased every year until it reached 2020, recording nitrite concentration slightly above 40 mg\L.

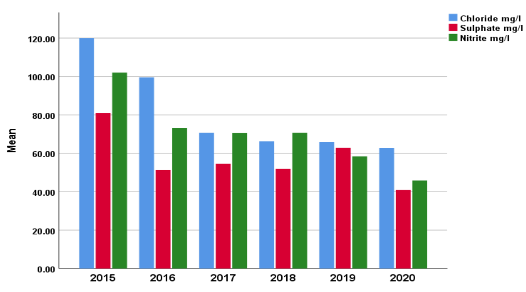

Fig. 29. Chloride, sulphate, and nitrite variables in location 6 (Demshly).

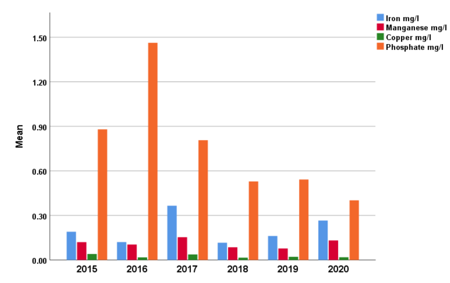

Fig. 30. Iron, manganese, copper, and phosphate variables in location no.6.

Fig. 30 represents the heavy metals detected in Demshly location (L6) from 2015 to 2020. The iron shows a significant change within the study time. In 2017, the concentration of iron was above the permissible limit (0.3 mg\L), while in the remaining years, the iron levels were below the permissible limit. The manganese and copper levels were below the permissible limits over the years, slightly changing yearly. The phosphate level in location six was similar to the level in location five, where the variation between the years was recorded shown in (**Fig. 30**), where the highest value was recorded (below 1.50 mg\L), and the lowest value was 0.45 mg\L in 2020.

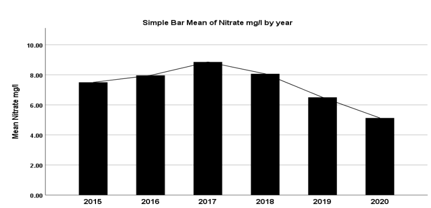

Fig. 31. Nitrate variable trend measured in location 6 (Demshly).

The nitrate variable shows a change from 2015 to 2020, where the highest value was recorded above 8.0 mg\L in 2017, while the lowest value was 5.0 mg\L in 2020 (**Fig. 31**).

3.1.7. Water quality change in Elkam location (L7).

The turbidity was measured in the Elkam location from 2015 to 2020, as represented in (**Fig. 32**). The turbidity levels show significant variation between the years; all the values were above the permissible limits, especially in 2015, 2016, and 2020. The pH levels had no significant change between the years, as shown in (**Fig. 32**).

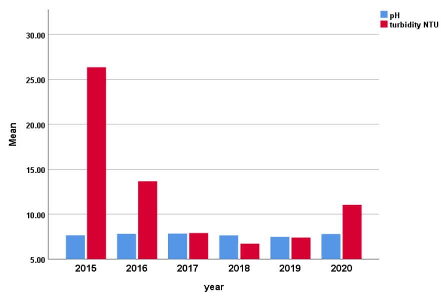

Fig. 32. pH and turbidity variables measured in Elkam location 2015- 2020.

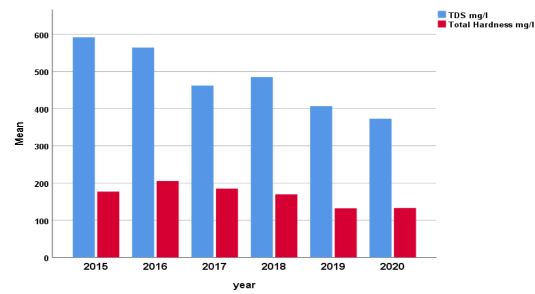

Fig. 33. TDS and total hardness variables measured in Elkam during 2015- 2020.

All the TDS values measured in the Elkam location were below the permissible limit (1000 mg\L); the values show a decreasing trend where the highest value was recorded in 2015 (below 600 mg\L), the lowest value was in 2020, below 400 mg\L. The total hardness values show a slight variation as most of the values were recorded below 200 mg\L, see (**Fig. 33**). Chloride levels were below the permissible limit (250 mg\L) with significant change during the years, where the highest values were recorded in 2015 and 206 (below 90 mg\L), and the other values were around 70.0 mg\L. The sulphate concentrations showed a significant change during 2015- 2020, as 2015 and 2019 were below 70.0 mg\L, and the lowest value was below 50.0 mg\L. Nitrite levels show high variation between 2020 and the remaining years and above the permissible limit, where the nitrite was below 40.0 mg\L, and the remaining values were in the range (60 – 70 mg\L), as shown in (**Fig. 34**).

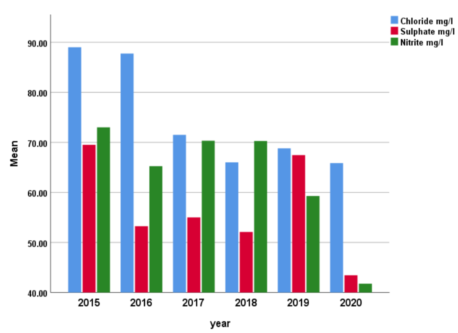

Fig. 34. Chloride, sulphate, and nitrite variables were detected in Elkam during 2015-2020.

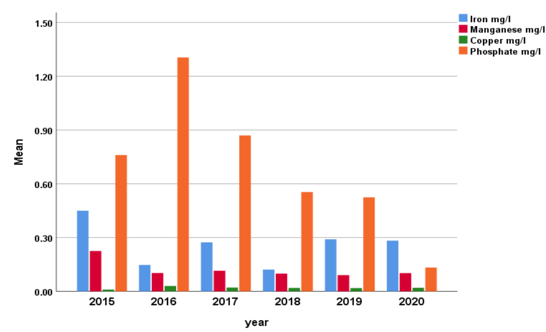

Fig. 35. Fe, Mn, Cu, and PO_4^{-2} measured in Elkam location during 2015-2020.

Fig. 35 represents the heavy metals level in the Elkam location; the mean iron concentrations were below the permissible limit except in 2015, as the highest iron level was recorded at 0.45 mg\L, while the lowest iron concentration was recorded above 0.1 mg\L in 2018. No significant changes have been shown in the manganese and copper concentrations below the permissible limits during the study period. The same trend and variation between the years for phosphate parameter were recorded in location seven, where the highest value was recorded (below 1.50 mg\L) in 2016, and the lowest value was (below 0.30 mg\L) in 2020 (**Fig. 35**).

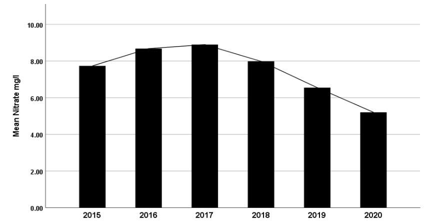

Fig. 36. Nitrate variable measured in Elkam location during 2015- 2020.

The nitrate concentration was below the permissible limits from 2015 to 2020. The maximum value was recorded above 8.0 mg\L in 2015 and 2017, while the lowest value was 5.0 mg\L in 2020, as shown in (**Fig. 36**).

3.1.8. Water quality change in Denshal location (L8)

pH measurements show no significant change in Denshal location during 2015- 2020, as represented in (**Fig. 37**). The turbidity variable levels were with no significant change during the study period as the maximum turbidity was above 12 NTU and the remaining values were around 12 NTU. All values were above the permissible limit of the turbidity (**Fig. 37**).

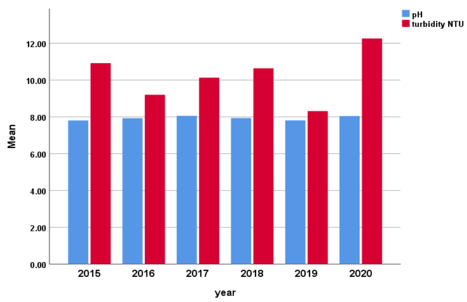

Fig. 37. pH and turbidity variables in Denshal location during 2015- 2020.

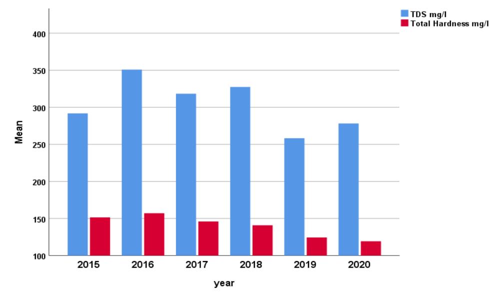

Fig. 38. TDS and total hardness variables measured in Denshal during 2015- 2020.

The TDS levels were below 350.0 mg\L from 2015 to 2020, Denshal was the first to get these low TDS values, and the lowest value was recorded in 2019 at above 250.0 mg\L. It is also noted that the low level of total hardness was recorded in Denshal during the study time, where the lowest value was recorded above 100.0 mg\L in 2020, as shown in (**Fig. 38**). **Fig. 39** shows the levels of chloride and sulphate in Denshal during 2015- 2020; the chloride level shows low concentrations during the study with a slight change lower than the permissible limit of drinking water limits (250 mg\L), especially in 2019 and 2020, as it was recorded below 30.0 mg\L. Sulphate levels in the Denshal location were below the permissible limit in all the study time, with a slight variation where the highest value was above 40.0 mg\L in 2016, and the lowest value was below 30 mg\L in 2020.

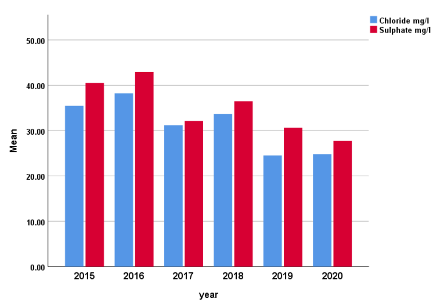

Fig. 39. Chloride and sulphate variables measured in Denshal during 2015- 2020.

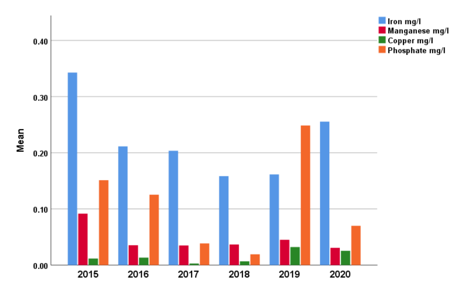

Fig. 40. Fe, Mn, Cu, and PO_4^{-2} metals variables in Denshal during 2015- 2020.

Denshal location shows contamination with iron levels, especially in 2015, where the iron concentration exceeded the permissible limit (0.3 mg\L) compared with other years where the iron level was below the permissible limit. Manganese and copper concentrations were below the permissible limits during the study time, as shown in (**Fig. 40**). The phosphate level in location no.8 shows a significant drop represented in Figure 58 with a slight variation as the highest value was recorded at 0.25 mg\L in 2019, and the lowest values were recorded in three years (2017, 2018, and 2020) below 0.10 mg\L.

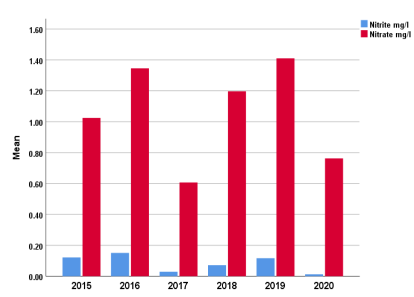

Fig. 41. Nitrite and nitrate variables in Denshal location during 2015- 2020.

The nitrite level in the Denshal location was recorded below the permissible limits (0.2 mg\L), as the first location had low nitrite values after nitrite pollution was recorded through the Rosetta branch. The lowest nitrite value was recorded in 2020, below 0.1 mg\L. The nitrate level shows a slight variation as the highest value was recorded at 1.4 in 2019, and the lowest was 0.6 mg\L in 2017, as shown in (**Fig. 41**).

3.1.9. Water quality change in Damanhur 1 location (L9).

Fig. 42 represents the pH and turbidity measured in location nine during 2015- 2020. The pH variable shows no significant variation between the years, where the pH levels were within the permissible limits (6.5- 8.5). The turbidity shows a slight variation between the years studied, where the variable level was above the permissible limit during all the study time. The TDS level was below 300.0 mg\L during the study time, except in 2016 and 2018 were recorded slightly above 300.0 mg\L, where the TDS values were within the permissible limit all the study time, as shown in (**Fig. 43**). The total hardness level was below 150.0 mg\L all study time.

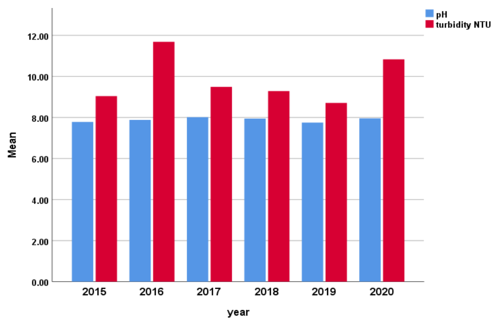

Fig. 42. pH and turbidity variables measured in location (L9) during 2015- 2020.

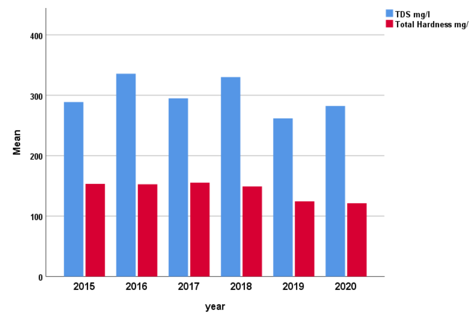

Fig. 43. TDS and total hardness variables measured in location (L9) during 2015- 2020.

Chloride concentration recorded in location nine is represented in (**Fig. 44**), where a slight variation was shown during the years. The chloride levels range was (30 – 40 mg\L), and the concentrations were below the permissible limit. The sulphate concentration shows a slight variation between the years, from 40.0 mg\L to below 30.0 mg\L, as represented in (**Fig. 44**). The nitrite level detected in L9 was below the permissible limit during all the study time with no significant variation. The nitrate level shows a slight variation, where the highest nitrate level was recorded at 2.5 mg\L in 2015, and the lowest was 1.2 mg\L in 2019, as shown in (**Fig. 45**).

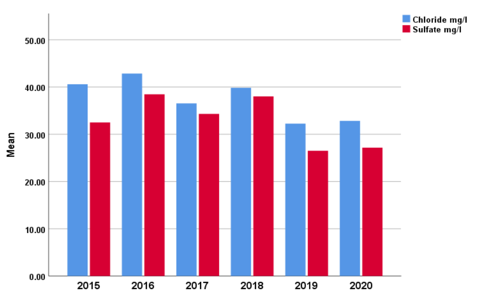

Fig. 44. Chloride and sulphate measured in Damanhur 1 location during 2015- 2020.

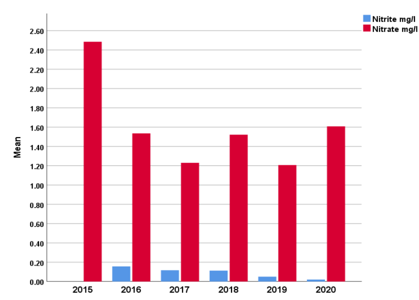

Fig. 45. Nitrite and nitrate variables detected in L9 during 2015- 2020.

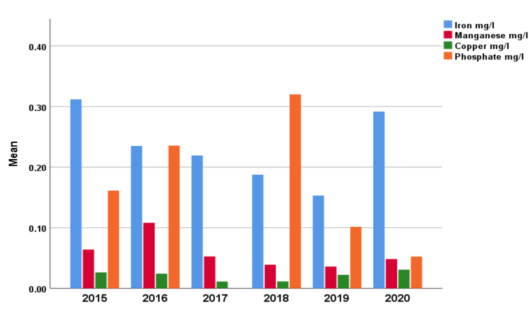

Fig. 46. Fe, Mn, Cu, and PO_4^{-2} detected in Damanhur 1 from 2015 to 2020.

The iron levels in Damanhur 1 location show substantial variation between the years; the iron level exceeded the permissible limit in 2015 and was below the permissible limit in the remaining period, as shown in (**Fig. 46**). Manganese and Copper levels were below the permissible limits during the study time, with no significant variation detected. The phosphate levels tend to be in lower concentration in location no.9, where the highest value was recorded (above 0.30 mg\L) in 2018, and the lowest values were recorded below 0.10 mg\L in 2019 and 2020. A significant drop was shown in 2017 as it was below the detection limit (**Fig. 46**).

3.1.10. Water quality change in Damanhur 2 location (L10).

Fig. 47 represents the pH and turbidity water quality variables measured in location 10 from 2015 to 2020, where the pH variable shows no change with the time change. The turbidity values show a slight change during the years, where all the values were above the permissible drinking water limits, and the turbidity ranged from 10.0 to 15.0 NTU. The TDS level was below 300.0 mg\L during the study time, except in 2016, slightly above 300.0 mg\L, where the TDS values were within the permissible limit all the study time, as shown in (**Fig. 48**). The total hardness levels in location 10 were below 150.0 mg\L all study time, with a slight decrease in 2019 and 2020, as represented in (**Fig. 48**).

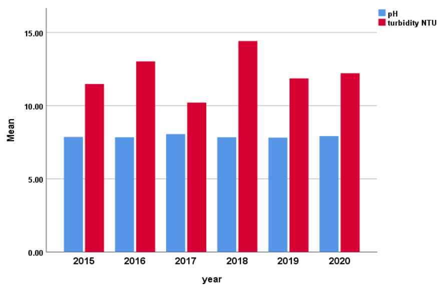

Fig. 47. pH and turbidity variables measured in Damanhur 2 from 2015 to 2020.

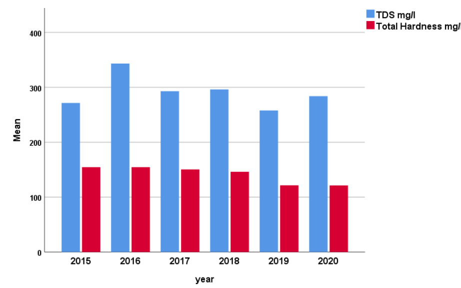

Fig. 48. TDS and total hardness variables in Location 10 during 2015- 2020.

Location 10 shows a lower concentration of chloride and sulphate ions. The chloride levels show significant variation with the time tested, where the highest value was recorded above 35.0 mg\L in 2016, and the lowest was below 25 mg\L in 2019. The same variation trend was shown in sulphate level in location 10, where the highest value was recorded below 45 mg\L in 2016, and the lowest value was below 30 mg\L in 2019, with significant variation recorded during the years shown in (**Fig. 49**).

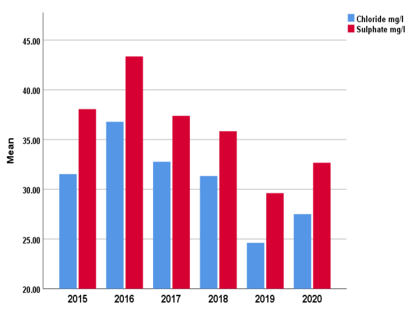

Fig. 49. Chloride and sulphate variables measured in Location 10 during 2015-2020.

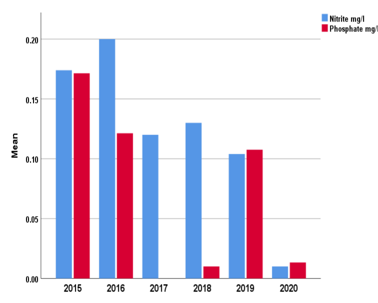

Fig. 50. Nitrite and phosphate levels in Location 10 during 2015- 2020.

The nitrite level in location 10 was below the permissible limit for drinking water during the whole study period, where the lowest values were recorded in 2015 and 2020, below 0.05 mg\L, as shown in (**Fig. 50**). The phosphate level shows a significant drop down in location no.10, as the highest value was recorded below 0.20 mg\L. The lowest values were recorded in 2017, 2018, and 2020 as below the detection limit.

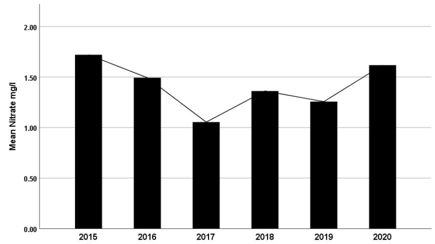

Fig. 51. Nitrate water quality level in Location 10 during 2015- 2020.

The nitrate level detected in location 10 was below the permissible limits with a slight change during the years, as shown in (**Fig. 51**), where the highest value was recorded at 1.7 mg\L in 2015, and the lowest value was 1.1 mg\L in 2017. **Fig. 52** shows the levels of the heavy metals that have been measured in location 10 from 2015 to 2020. The iron concentration shows significant variation during the years, where the highest iron level was measured in 2016 and was above the permissible drinking water limit, while the remaining data were below the limit and acceptable. The Mn and Cu concentration shows a slight variation in the acceptable limit of the two metals.

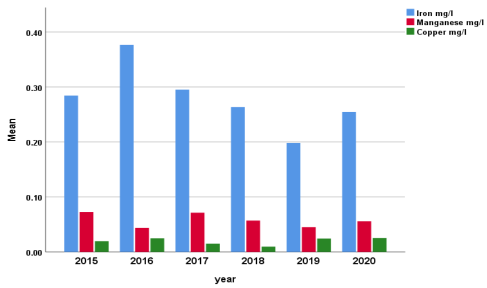

Fig. 52. Fe, Mn, and Cu metals measured in location 10 from 2015 to 2020.

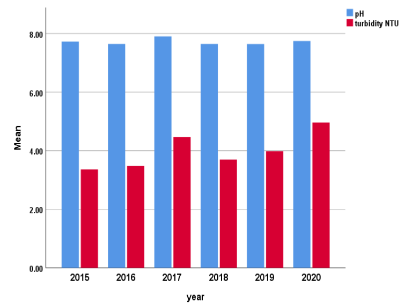

Fig. 53. pH and turbidity variables measured in location 11 during 2015- 2020.

3.1.11. Water quality change in Edfina location (L11).

Fig. 53 represents the pH and turbidity of water quality variables measured in location 11 during 2015- 2020. The pH variable showed no significant change during the years and was within the permissible limit range (6.5- 8.5). The turbidity variable shows a slight variation, where the turbidity ranged from 3.0 to 5.0 NTU, as the highest value was recorded in 2020, and the lowest values were below 4.0 NTU in 2015 and 2016. The TDS variable level increased compared with TDS values in location 10, where the highest value was below 500 mg\L, and the lowest value was below 400 mg\L in 2020. (**Fig. 54**) represents the significant variation between the years according to TDS levels. While for the total hardness values, no significant variation was recorded during the time tested, as the total hardness values ranged from 150 to 200 mg\L.

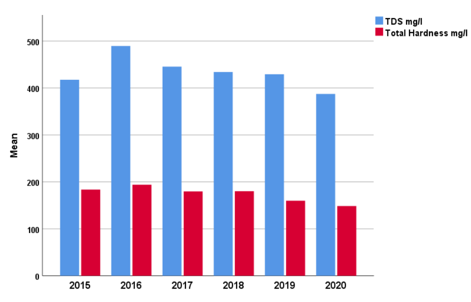

Fig. 54. TDS and total hardness measured in location 11 from 2015 to 2020.

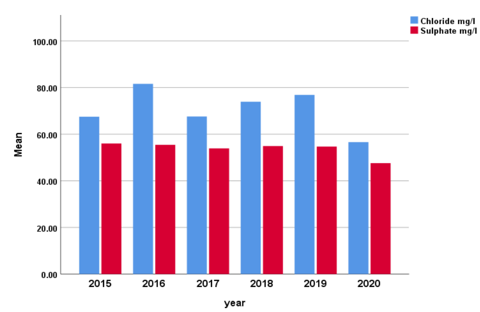

Fig. 55. Chloride and sulphate variables levels in location 11 from 2015 to 2020.

The chloride values measured in location 11 are doubled the value in location 10 in specific years, where the values show significant variation during the years as the highest value was above 80 mg\L in 2016. The lowest was below 60 mg\L in 2020, as shown in (**Fig. 55**). The sulphate level shows no variation with the time tested, as the sulphate concentration was below 60 mg\L all the years except in 2020, as the level dropped slightly to below 50 mg\L.

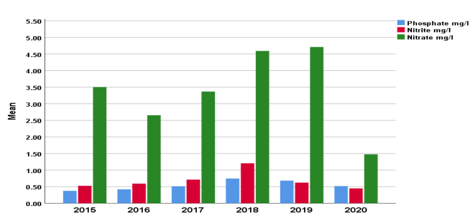

Fig. 56. Nitrite, nitrate, and phosphate variables in location 11 from 2015 to 2020.

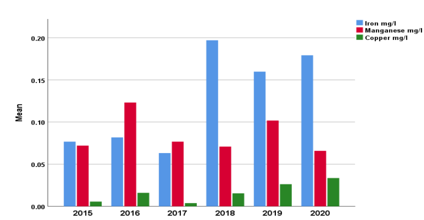

Fig. 57. Fe, Mn, and Cu variables detected in location 11 from 2015 to 2020.

Nitrite concentration measured in location 11 was above the permissible limits all the study time from 2015 to 2020 and showed significant variation, increasing more than 1.0 mg\L in 2018. The nitrate values were lower than the permissible limit, showing significant variation between the years. The nitrate levels were above 4.5 mg\L in 2018 and 2019, and the lowest value was detected at 1.5 mg\L in 2020, as shown in (**Fig. 56**). The phosphate concentration showed a significant increase compared with the previous locations, where the highest values were recorded below 1.0 mg\L in 2018 and 2019, and the lowest values were observed below 0.50 mg\L in 2015 and 2016. The heavy metals detected in location 11 were below the permissible limits during the study period, same with location 1, where all the metals show a slight variation between the years (see **Fig. 57**).

3.1.12. Water quality change in Badr location (L12).

The turbidity parameter measured in location twelve from 2015 to 2020 shows a slight variation where the lowest value recorded in 2015 was below 7.0 NTU and the highest value was above 10.0 NTU. pH parameter shows no significant variation and was in the permissible range for the drinking water limit (see **Fig. 58**).

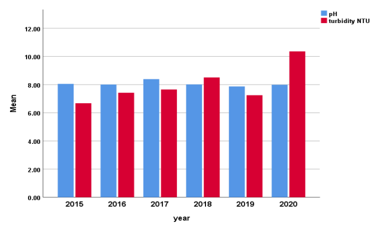

Fig. 58. pH and turbidity variables measured in location 12 during 2015- 2020.

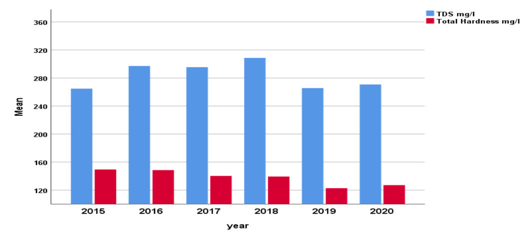

Fig. 59. TDS and total hardness measured in location 12 from 2015 to 2020.

The TDS concentration recorded in Location twelve was the lowest in the study area, as shown in (**Fig. 59**), where the values show a slight variation among the years, as the highest value was recorded below 320.0 mg/L in 2018. The total hardness concentration decreased during the years when the lowest value was recorded, 120 mg/L in 2019. The chloride and sulphate detected in location twelve show weak concentrations compared with other sites. The chloride concentration had significant variation during the years, as the highest value was measured below 40.0 mg/L in 2015, and the lowest was above 20.0 mg\L in 2020. The sulphate level shows no variation between the years, and most of the concentration was below 40.0 mg\L (see **Fig. 60**).

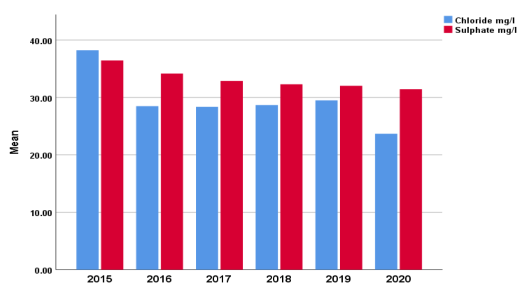

Fig. 60. Chloride and sulphate variables measured in location 12 (2015- 2020).

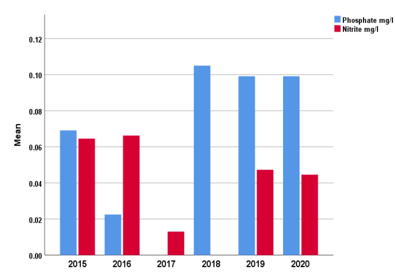

Fig. 61. Nitrite and phosphate variables levels in location 12 from 2015 to 2020.

The nitrite level measured in location twelve was below the permissible drinking water limit during the study time. The nitrite concentration showed no variation detected as the level was below 0.08 mg\L, as shown in (**Fig. 61**). The phosphate concentration in location no.12 showed a significant drop down represented in (**Fig. 61**), where the highest values were above 0.06 mg\L in 2015 and 2016 and below the detection limit in 2017, 2018, 2019, and 2020.

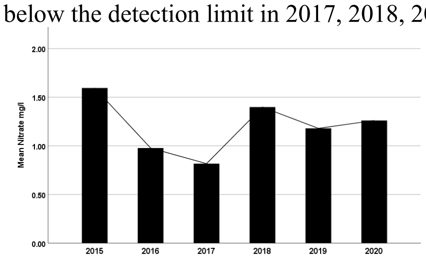

Fig. 62. Nitrate water quality variable measured in location 12 (2015- 2020).

The nitrate concentration measured was below the drinking water permissible limit during the whole study period. A slight variation was detected between the years where the highest value was recorded above 1.5 mg\L in 2015, and the lowest value was below 1.0 mg\L in 2017 (see **Fig. 62**). **Fig. 63** shows the heavy metals measured in location twelve from 2015 to 2020. A significant variation was detected in Fe concentration, while in 2016, the iron level was above the drinking water limits compared with the other years where the concentration was below the limit. The lowest Fe value was recorded at 0.10 mg\L in 2015, and the highest was 0.37 mg\L in 2016. The Mn and Cu were within the permissible limits during the study time, slightly varying between the years.

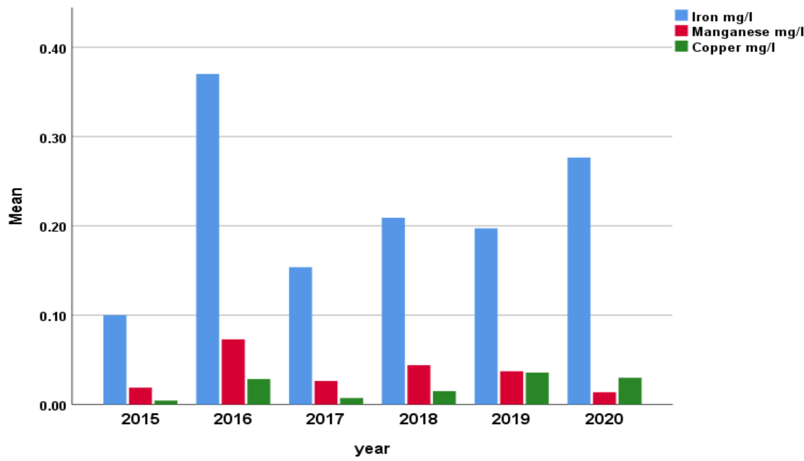

Fig. 63. Fe, Mn, and Cu metals measured in location 12 (2015- 2020).

4. Conclusion

Location no.1 shows an increase in water quality parameters Cl^-, SO_4^{-2}, Nitrite, and TDS in 2016 and a significant increase in turbidity in 2020, while the Iron shows a significant increase in 2017 compared with other years. For location no.2, the turbidity shows a slight increase in 2019 and 2020, while the chloride, TDS, and nitrite shows a significant increase in the last three years. The remarkable year was for iron and nitrate, wherein 2017 was the highest increase for iron, and the year 2020 was the significant increase in nitrate.

Location no. 3 shows significant turbidity, TDS, and Chloride increase in 2015 and 2020. While a remarkable change was recorded for iron level during the whole study time, the nitrate was the only parameter showing a decreasing trend; the lowest value was recorded in 2020. Many water quality variables measured in location no.4 showed remarkable variations in turbidity, TDS, chloride, and iron, especially in 2020.

2015 and 2016 showed a remarkable increase in location 5 variables like turbidity, TDS, chloride, and sulphate, while the year 2020 was the significant year for iron level and the year 2019 for nitrite level. Location no.6 turbidity shows a significant increase in 2015 and 2020, while the TDS, chloride, and nitrite significantly decreased. Moreover, the iron level was recorded in 2017 with a remarkable change according to other years.

Location no.7 showed significant variation in turbidity and iron in 2015 as the highest value compared with other years. The decreasing trend showed again in TDS, chloride, manganese, and nitrite from 2015 to 2020. Location no.8 showed variation among the years with no significant variation compared with previous locations, except for the iron concentration recorded in 2015 as the highest value. Also, location no.8 was the first site with the nitrite and nitrate concentration that showed a remarkable decrease below the permissible limits compared with previous sites.

Location no. 9 & 10 showed a slight variation for most of the variables detected, and the most remarkable variation was for chloride and sulphate, where the lowest values were recorded in 2019 and 2020. Moreover, a significant decrease was recorded in nitrite levels in 2020. Location no.11 showed no significant variation as most of the variables were below the permissible limits except nitrite concentration was above the permissible limit all the study period, and a significant increase in phosphate level compared with previous locations. Location no.12 showed no significant variation as most of the variables were below the permissible limits compared with other locations, except for Fe concentration was above the permissible limit in 2016, and the lowest drop was recorded for nitrite level in 2018.

The Rosetta branch water quality is getting worse as shown in locations L3, L4, L5, L6 and L7 with the time change in reverse with the situation in the sub canals (Rahay El Nasery and Khandaq sharky), where the water quality remains stable without any significant increase or decrease on the water quality.

The waterways in Egypt are numerous, from the main artery of the Nile River to the main branches, such as the Rosetta branch and different sub canals. With untreated agricultural and sanitary drainage, the water quality in the Nile is greatly affected. The Rosetta branch was negatively and directly affected by the pollutants of the Rahawy drain and notes the annual decline in water quality, which constitutes a real threat if the current situation continues.

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Competing interests

The authors declare no competing interests.

Authors' contributions

Ahmed M. K. AbouHalima designed the study, performed the searches, screened investigations for eligibility, extracted the data, drafted the manuscript, and Yingxia LI critically revised the manuscript. The final version got approval from all authors.

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