



ASSESSMENT OF WATER QUALITY AT THE INTAKE OF EL-TABIA INDUSTRIAL COMPLEX

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ABSTRACT- El-Tabia industrial complex comprises general company for paper production Rakta, the National Paper Company, Abu Qir Fertilizers and Chemical Industries Comapny and Abu Qir thermal power station. El-Tabia industrial complex takes its raw water from Rakta water canal. Along its course, Rakta canal receives pollution from point and non-point sources. This pollution leads to significant deterioration of the quality of the water in Rakta canal. So, there was a need for this study to assess the suitability of the water quality of Rakta canal as a water intake for these industries. Furthermore, to identify the sources of pollution which made it unfit for its uses and to assess their impact on water quality. As the same time, evaluation of the in-plant water treatment efficiency was carried out. Setting an outline for an environmental protection plan for the Rakta canal and proposing a monitoring scheme were developed. A bench scale study for hardness removal using single stage treatment and two stage split treatment was carried out. The analysis of data was done by Stat Graphics program using the second degree polynomial regression, to obtain the polynomial regression equation and response surface (CaO and Na_2CO_3 doses were the independent variable). Steepest ascent technique was used to obtain the dose combination which produces the highest percent of hardness removal.

INTRODUCTION

This paper will outline the assessment of the suitability of the water quality of Rakta Canal as a water intake for El-Tabia industrial complex.

Furthermore, identify the sources of pollution which make it unfit for its uses and assess their impact on water quality. At the same time, evaluation of the in-plant water treatment efficiency has been carried out. Setting an outline for an environmental protection plan for the Rakta Canal and proposing a monitoring scheme has been developed. This system provides an early warning in case of accidental pollution to enable taking appropriate actions without interruption of the strategic industries in this area.

EXPERIMENTAL WORK

Sampling covered a period of 6 months from October 1995 to March 1996. Six sets of water samples were collected from different locations along the Rakta Canal as in figure (1).

- Location 1** : The entrance of Rakta canal
- Location 2** : Beside Abu-Zeid village
- Location 3** : Beside El-Batanuni village
- Location 4** : Beside El-Arba' Ezab village
- Location 5** : Beside Nag' El-Amia village
- Location 6** : The distribution well
- Location 7** : In the vicinity of Ali-Baba gum factory and Nashat basha village
- Location 8** : The water intake of the National Paper Co.
- Location 9** : The water intake of Rakta Paper Co.
- Location 10** : The point where the Rakta canal is changed to underground pipe.
- Location 11** : The water intake of Abu Qir Thermal Power Station
- Location 12** : The treated process water of the National Paper Co.
- Location 13** : The treated process water of Rakta Co.

Bench Scale for Hardness Removal (Softening)

Experimental work of the bench scale : Three grab samples (10 liters each) were collected from the raw water of Rakta Canal.

- ♦ Laboratory analysis was carried out to determine the composition of each sample concerning hardness, alkalinity, sodium, sulfate, and carbon dioxide.
- ♦ Concentrations were calculated as meq/l.
- ♦ The composition of each water sample was represented by a bar diagram.
- ♦ The required chemicals for softening were calculated for each water sample by applying two treatment methods.
 - (a) Single stage softening.
 - (b) Two stage split treatment softening.
- ♦ The jar tests⁽¹⁾ were applied for each water sample by each treatment.
- ♦ In order to conduct the jar tests, lime and soda ash were applied simultaneously in one stage softening and separately in two stage split treatment softening.

The following plan is the factorial experiments of the chemical addition.⁽²⁾

Experimental Design for Softening									
Softener	Cont.	Different Doses Jar Test							
Lime	0	+	-	C	-SQ	C	+	-	+SQ
Soda ash	0	+	+	C	C	-SQ	-	-	C

The calculated doses of lime and soda ash were defined as center doses. High, low, and center dosage were selected for both lime and soda ash and were designed as "+", "-", and "C".

Two additional doses were needed +SQ and -SQ. These are calculated as follows:

"C" = Center dose = Calculated dose

"+" = High dose = C +60%

"-" = Low dose = C -60%

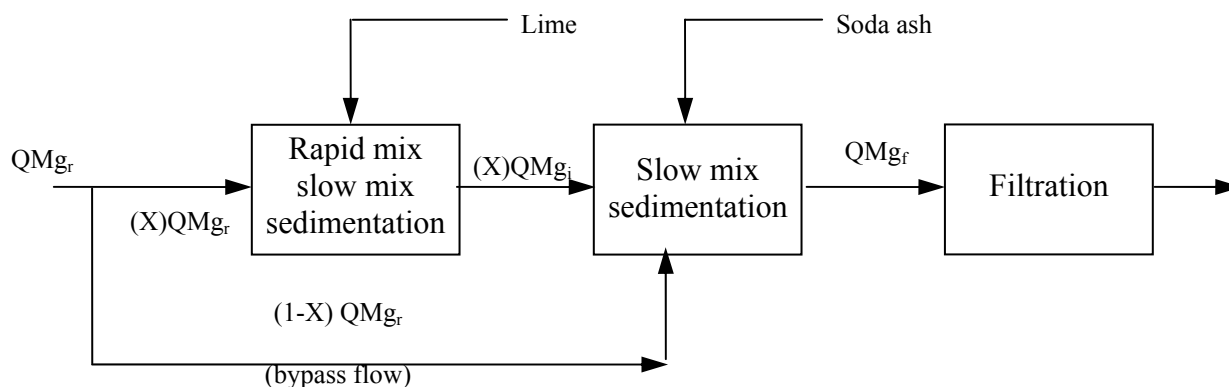
Analysis of data : Following the completion of laboratory experiments, statgraphics programe was used to calculate response surfaces, and equations. These equations presented the hardness removal percentage as a

function of chemical dose. Steepest ascent technique was used to obtain the dose combination which produces the highest percent of hardness removal⁽³⁾.

$$"+SQ" = C + \frac{\sqrt{2}}{2} \quad [\text{High dose-low dose}]$$

$$"-SQ" = C - \frac{\sqrt{2}}{2} \quad [\text{High dose-low dose}]$$

- ◆ According to the presented factorial design plan, doses of lime and soda ash were applied to the jars.
- ◆ In two stage split treatment, a flow diagram for a typical split treatment lime softening process is presented in the figure below.



Depending on the desired finished water magnesium concentration, treated flow fraction was determined from the following equation:

$$\therefore X = \frac{Mg_f - Mg_r}{Mg_i - Mg_r}$$

Where:

Q = Quantity of treated water

X = Proportion of treated water

Mg_r = Magnesium concentration in raw water

Mg_i = Magnesium concentration in first stage effluent

Mg_f = Magnesium concentration in finished water

RESULTS AND DISCUSSION

Study of the Quality of Rakta Canal Water

Table (I) & (II) represent mean, standard deviation and range values of the physical and chemical analysis of Rakta Canal at different sampling locations and at different surveyed months, respectively.

From tables (I) and (II), it was noticed that:

- The increase in several pollution parameters such as turbidity which was high in location 2, 3, and 10.
- The increase in the biochemical oxygen demand, and chemical oxygen demand, which were over the permissible limits in the Egyptian law number 48, 1982 article (60)⁽⁴⁾.
- The increase in the T.D.S, hardness, and silicates in Rakta Canal beside the garbage dumps.
- The increase in the phosphates and sulphates during the fertilization periods and Winter closure period.
- The decrease in the dissolved oxygen in location number 7 in the vicinity of Ali-Baba gum factory due to the discharge of high strength wastes.

Comparison between quality before and after the water treatment plants in the Rakta Company and the National paper company:

Tables (III) & (IV) represent mean, standard deviation, differences and paired t of influent and effluent of the water treatment plant in Rakta Co. and the National paper Co. respectively.

From tables (III) and (IV), it was noticed that:

The comparison between before and after process water treatment in the National paper company and Rakta company showed decrease in turbidity and phosphates values with the increase in D.O. values. There was decrease in silicates values in case of the National paper company.

The industrial process water was within the permissible limits for paper production in turbidity, chlorides, silicates, and sulphates. While it was higher than the permissible limits for paper production in T.D.S., alkalinity, total hardness, calcium hardness, and magnesium hardness.

Management plan for environmental protection of Rakta Canal

The importance of Rakta Canal as the water intake for El-Tabia industrial complex stimulates the need for development and implementation of a comprehensive environmental protection plan for this important water source.

Legal issues : The protection of water streams requires adequate legislation. To achieve effective enforcement of environmental laws pertinent to protection of water resources, industry and regulatory agencies must work together in a cooperative and expeditious manner.

Monitoring scheme : Continuous monitoring is essential to provide an early warning in case of abnormal rise of pollutants or accidental spills. This stimulates prompt corrective actions without interruption of industrial production or power generation in this area.

Committee for management of Rakta Canal : A joint committee representing industries, water users of Rakta Canal, should be assigned the responsibility of proposing proper actions in case of emergencies involving significant deterioration of water quality of the canal.

The committee should be also able to provide the enforcement agencies with the necessary information and recommendations to implement these actions.

It is a public responsibility to protect water resources at the Rakta canal and maintain it of suitable quality and sufficient quantity to sustain industrial production and other development projects which depend on the canal for water supply. Large manufacturing establishments in El-Tabia industrial complex being the main users of the Rakta canal water, should also participate in implementation of an integrated management scheme for this vital water resource.

Monitoring scheme of Rakta Canal

Rakta canal is a branch of El-Mahmoudia canal which originates from the Rosseta branch of the River Nile. Along their courses, Rakta and El-Mahmoudia canals receive pollutants from point and non-point sources. These pollutants lead to significant deterioration of the quality of the water in either Rakta canal or El-Mahmoudia canal.

Consequently, monitoring must be applied to assess the suitability of water quality in El-Mahmoudia canal as a source of water to all Alexandria water canals. At the same time, monitoring must be applied to assess the suitability of water quality in Rakta canal as a water intake for El-Tabia industrial complex.

In case of El-Mahmoudia canal, Alexandria Water Authority is considered responsible for monitoring the water quality along its course. With regard to Rakta canal, the joint committee representing industries, using water from Rakta canal, should be assigned the responsibility for follow-up of water quality monitoring of Rakta canal. Water quality monitoring will provide data to detect magnitude and sources of pollutants. In addition, regular monitoring is undertaken by the Ministry of Health for follow-up of the water quality in El-Mahmoudia canal to ensure its suitability for human consumption, while the Ministry of Public works and Water resources monitors the water quality of Rakta canal and El-Mahmoudia canal with the context of its responsibility for enforcing law 48/1982.

In case of violations, the regulatory authorities inform the surface water police to implement penalties against individuals or establishments.

In case that no action is taken to stop violation, the problem has to be identified by the joint committee (for Rakta canal) or Water Authority (for El-Mahmoudia canal). According to the problem characteristics, the related governmental agencies are allocated to cooperate together to set a framework to solve the problem. These governmental agencies could be, Ministry of Industry, Ministry of Public Works and water Resources, Ministry of Agriculture, Ministry of Health, and Ministry of Information.

The proposed monitoring scheme for Rakta canal comprises the following:

(a) Sampling locations : Samples from stationary stations of Rakta canal should be regularly monitored. The recommended five locations (see figure 1) are as follows:-

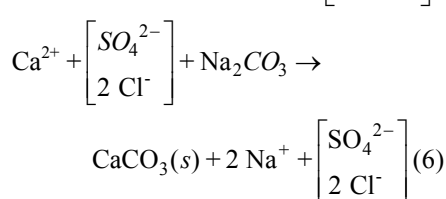
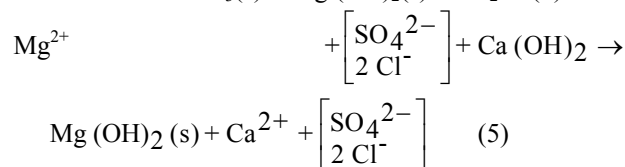
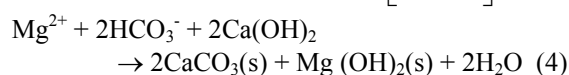
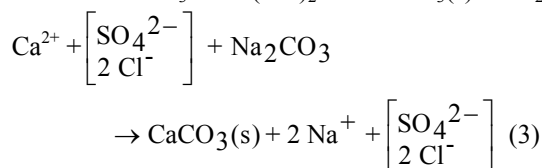
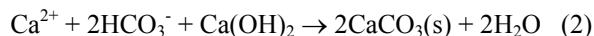
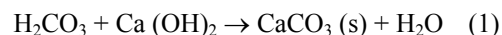
- (i) Location number 1 (ii) Location number 6
- (iii) Location number 8 (iv) Location number 9
- (v) Location number 10

(b) Sampling frequency: Sampling frequency depends on the parameters selected as indicators of

pollution and the probability of significant changes in their values.

Bench scale study for hardness removal (softening)

In the lime-soda ash softening process, lime is added to provide the hydroxide ions required to elevate the pH, while sodium carbonate is added to provide an external source of carbonate ions. The least expensive form of lime is quicklime (CaO), which must be hydrated or slaked to Ca (OH)₂ before application. These reactions of lime-soda ash softening process are:



Equation (1) represents the neutralization reaction between free carbon dioxide or carbonic acid and lime that must be satisfied before the pH can be increased significantly. The removal of calcium carbonate hardness is reflected in Eq (2). Equation (3) represents the removal of calcium non-carbonate hardness. Equation (4) is somewhat similar to Eq (2) in that it represents the removal of carbonate hardness, except in this case it is magnesium carbonate hardness. Equation (5) represents the removal of magnesium non carbonate hardness. In this reaction, however, there is no net change in the hardness level because for every magnesium ion removed a calcium ion is added. This is illustrated in Eq. (6) which is identical to Eq. (3).

Based on Eqs. (2) to (6), the chemical requirements for lime-soda ash softening can be summarized as follows if all constituents are expressed as equivalent CaCO₃: 1 mg/L of lime as CaCO₃ will be required for each milligram per liter of carbonic acid (expressed as CaCO₃), 1 mg/L of lime as CaCO₃ will be required for each milligram per liter of calcium carbonate hardness present, 1 mg/L of soda ash as CaCO₃ will be required for each milligram per liter of calcium non-carbonate hardness present, 2 mg/L of lime as CaCO₃ will be required for each milligram per liter of magnesium carbonate hardness present, 1 mg/L of lime as CaCO₃ and 1 mg/L of soda ash as CaCO₃ will be required for each milligram per liter of

magnesium non-carbonate hardness present. To achieve removal of magnesium in the form of $\text{Mg}(\text{OH})_2$ (s), the solution pH must be raised to a value greater than 10.5. This will require a lime dosage greater than the stoichiometric requirements (1.0 to 1.25 meq/L)⁽⁵⁾.

The bench scale study was conducted using Jar test by applying two different methods for water softening.

(a) Single stage treatment

(b) Split treatment

The following steps were used:

(i) Carbon dioxide, cations and anions were measured : The results of laboratory analysis for water sample no. 1 indicates that the water sample composition was as follows:

The species concentration in milliequivalents per liter is calculated from the relationship⁽¹⁾

$$\text{meq/L of species} = \frac{\text{mg / L of species}}{\text{Equivalent weight of species}}$$

Species	mg/l	Eq. wt.	meq/l
CO_2	6.6	22	0.3
Mg^{2+}	24.3	12.15	2.0
Ca^{2+}	46.0	20.0	2.3
Na^+	34.27	23.0	1.49
HCO_3^-	220.0	61.0	3.6
SO_4^{2-}	38.4	48.0	0.8
Cl^-	53.0	35.5	1.49

(ii) Doses of lime and soda ash were calculated:

The finished water hardness = 100 mg/l as $\text{CaCO}_3 = 2.0$ meq/l with a maximum Mg-hardness ≈ 40 mg/l as $\text{CaCO}_3 = 0.8$ meq/l.

Due to limited reaction-settling time, turbulence within the system, etc. effluent concentration of these chemicals exceed theoretical solubility values. Therefore, practical solubility limits (PSL) are commonly used. Based on operational data;

PSL of $\text{Mg}^{2+} = 0.2$ meq/l

PSL of $\text{Ca}^{2+} = 0.6$ meq/l

Also, in order to force the magnesium to precipitate, an excess of 1.0-1.25 meq/l of hydroxyl ions are provided. So, there are 1.25 meq/l Na_2CO_3 will be required to react with the excess lime added for Mg^{2+} removal. Since Mg^{2+} will be accordingly = 0.2 meq/l.

So, to keep finished water hardness = 2.0 meq/l

$\therefore \text{Ca}^{2+}$ should be = 1.8 meq/l

Since PSL of $\text{Ca}^{2+} = 0.6$ meq/l

\therefore Quantity of Ca^{2+} in finished water = 1.8-0.6 = 1.2 meq/l

\therefore Accordingly Na_2CO_3 must be reduced 1.2 meq/l

\therefore The modified quantity of $\text{Na}_2\text{CO}_3 = 1.25 - 1.2 = 0.05$ meq/l

(a) Single stage treatment : The doses of lime and soda ash were calculated.

$\therefore \text{Ca}(\text{OH})_2 = 0.3 + 2.0 + 2.0 + 1.5 + 1.25 = 7.05$ meq/l

$\therefore \text{Na}_2\text{CO}_3 = 0.8 + 0.05 = 0.85$ meq/l

The chemical doses sample 1:

$\therefore \text{CaO}$ (purity 85%) = 232.57 mg/l

$\therefore \text{Na}_2\text{CO}_3$ (purity 98%) = 45.974 mg/l

The chemical dose of sample 2:

CaO (purity 85%) = 215.4 mg/l

Na_2CO_3 (purity 98%) = 40.6 mg/l

The chemical dose of sample 3:

CaO (purity 85%) = 223.3 mg/l

Na_2CO_3 (purity 98%) = 34.0 mg/l

\therefore Mean CaO dose ≈ 225 mg/l

\therefore Mean $\text{Na}_2\text{CO}_3 \approx 35$ mg/l

The bench scale was conducted using Jar test doses and results are presented in table (VIII).

(b) Split treatment : The doses of lime were calculated.

Quantity of lime added = 0.3 + 2.0 + 2.0 + 1.5 + 1.25 = 7.05 meq/l

i.e. $\text{OH}^- = 7.05$ meq/l $\text{Ca}^{2+} = 2.3 + 7.05 = 9.35$

$$\therefore X = \frac{0.8 - 2.0}{0.2 - 2.0} = \frac{1.2}{1.8} = 0.67\%$$

Where X = treated portion of water

\therefore Blended water

Treated		Bypassed	
Mg^{2+}	= 0.67 (0.2)	+ 0.33 (2)	= 0.794
CO_2	= 0.67 (0)	+ 0.33 (0.3)	= 0.099
Ca^{2+}	= 0.67 (2.65)	+ 0.33 (2.3)	= 2.5345
Na^+	= 0.67 (1.49)	+ 0.33 (1.49)	= 1.49
OH^-	= 0.67 (1.45)	+ 0.33 (0)	= 0.9715
CO_3^{2-}	= 0.67 (0.6)	+ 0.33 (0)	= 0.402
HCO_3^-	= 0.67 (0)	+ 0.33 (3.5)	= 1.155
SO_4^{2-}	= 0.67 (0.8)	+ 0.33 (0.8)	= 0.8
Cl^-	= 0.67 (1.49)	+ 0.33 (1.49)	= 1.49

$\therefore \text{Ca}^{2+} = 1.2885 + 0.4825 = 1.771$

$\text{OH}^- = 0.2 + 0.4825 = 0.6825$

Since $\text{HCO}_3^- + \text{OH}^- \rightarrow \text{CO}_3^{2-} + \text{H}_2\text{O}$

$$0.4825 \quad 0.4825 \quad 2 \times 0.4825$$

$\therefore \text{OH}^- = 0.6825 - 0.4825 = 0.2$

$\text{CO}_3^{2-} = 0.6 + 2 \times 0.4825 = 1.565$

$\text{Ca}(\text{OH})_2 = 7.05$ meq/L

$$= 7.05 \times \frac{74.08}{2} = 261.132 \text{ mg / l}$$

\therefore Dose in $\text{CaO} = 261.132 \times \frac{56.08}{74.08} = 197.682$ mg / l

\therefore Dose in CaO (85% purity)

$$= 197.682 \times \frac{100}{85} = 233.567$$

Since treated portion = 67% \therefore Dose = 155.81993

The second dose $\text{Ca}(\text{OH})_2 = 0.4825$ meq/l

\therefore Dose of CaO (purity 85%) = 15.9168 meq/l

\therefore Total dose = 155.81993 + 15.9168

(as CaO purity 85%) = 171.73673 mg/l CaO

\therefore Total dose (as CaO purity 85%) for sample No. 1 = 171.73673 mg/l CaO

\therefore Total dose (as CaO purity 85%) for sample No. 2 = 155.43600 mg/l CaO

\therefore Total dose (as CaO purity 85%) for sample No. 3 = 155.28200 mg/l CaO

\therefore Mean dose ≈ 160 mg / l CaO Mean treated portion $\approx 60\%$

Soda ash will added as external source of carbonate ions.

The bench scale for split treatment was conducted. The results are presented in table (IX).

Statistical analysis of bench scale data

The results were used for fitting the response surface using second degree polynomial regression equations. One stage can be applied in the range (CaO = 103-126 mg/l, Na₂CO₃ = 7-63 mg/l), while two stage split treatment can be applied in the range (CaO = 90-275 mg/l, Na₂CO₃ = 7-65 mg/l). These results were as follows:

(a) **Total hardness** : Table (VII) shows that the effect of CaO dose was highly significant ($F_{1, 21} = 12.70$, $p < 0.01$) and very highly significant ($F_{1, 21} = 21.45$, $p < 0.001$) in the one stage and split treatment, respectively. While the effect of Na₂CO₃ dose was highly significant ($F_{1, 21} = 14.57$, $p < 0.01$) in the split treatment only and non-significant in one stage treatment.

Table (VII): Bench scale statistical analysis results

		One stage	Split treatment
T.H.	CaO	Highly significant	Very highly significant
	Na ₂ CO ₃	Non significant	Highly significant
Ca.H.	CaO	Significant	Highly significant
	Na ₂ CO ₃	Significant	Very highly significant
Mg.H.	CaO	Highly significant	Significant
	Na ₂ CO ₃	Non significant	Non significant

Polynomial regression equation for the one stage experiment was as follows:

$$\hat{Y}_{T.H.} = -241.215 + 1.96891 \text{ CaO} + 2.1281 \text{ Na}_2\text{CO}_3 - 0.00336365 \text{ CaO}^2 - 0.00628515 \text{ CaO} * \text{Na}_2\text{CO}_3 - 0.007133 \text{ Na}_2\text{CO}_3^2$$

Polynomial regression equation for the split treatment experiment was as follows:

$$\hat{Y}_{T.H.} = 53.2319 - 0.436958 \text{ CaO} - 0.182212 \text{ Na}_2\text{CO}_3 + 0.00160083 \text{ CaO}^2 + 0.00189583 \text{ CaO} * \text{Na}_2\text{CO}_3 + 0.00159642 \text{ Na}_2\text{CO}_3^2$$

Where $\hat{Y}_{T.H.}$ = percent removal of total hardness

Note: These equations are applicable within limited range of CaO and Na₂CO₃ doses.

(b) **Calcium hardness** : Table (VII) shows that CaO dose effect was significant ($F_{1, 21} = 7.38$, $p < 0.05$), and highly significant ($F_{1, 21} = 12.86$, $p < 0.01$) in one stage and split treatment, respectively, while Na₂CO₃ dose effect was significant ($F_{1, 21} = 5.83$, $p < 0.05$) and very highly significant ($F_{1, 21} = 20.26$, $p < 0.001$) in one stage and split treatment, respectively.

Polynomial regression equation for one stage experiment was as follows:

$$\hat{Y}_{Ca.H.} = -381.727 + 3.19865 \text{ CaO} + 3.06413 \text{ Na}_2\text{CO}_3 - 0.00582876 \text{ CaO}^2 - 0.00898784 \text{ CaO} * \text{Na}_2\text{CO}_3 - 0.00926288 \text{ Na}_2\text{CO}_3^2$$

Polynomial regression equation for split treatment was as follows:

$$\hat{Y}_{Ca.H.} = 9.025668 + 0.301085 \text{ CaO} + 0.391621 \text{ Na}_2\text{CO}_3 - 0.00041 \text{ CaO}^2 - 0.0011875 \text{ CaO} * \text{Na}_2\text{CO}_3 + 0.0017487 \text{ Na}_2\text{CO}_3^2$$

Where $\hat{Y}_{Ca.H.}$ = percent removal of calcium hardness.

Note: These equations are applicable within limited range of CaO and Na₂CO₃ doses.

(c) **Magnesium hardness** : Table (VII) shows that CaO dose effect was highly significant ($F_{1, 21} = 13.70$, $p < 0.01$) and significant ($F_{1, 21} = 6.24$, $p < 0.05$) in one stage and split treatment, respectively, while Na₂CO₃ dose effect was non-significant in either one stage or split treatment.

Polynomial regression equation for one stage experiment was as follows:

$$\hat{Y}_{Mg.H.} = -37.5815 + 0.160477 \text{ CaO} + 0.985636 \text{ Na}_2\text{CO}_3 + 0.00034 \text{ CaO}^2 - 0.00304 \text{ CaO} * \text{Na}_2\text{CO}_3 - 0.004413 \text{ Na}_2\text{CO}_3^2$$

Polynomial regression equation for split treatment experiment was as follows:

$$\hat{Y}_{Mg.H.} = 99.2682 - 1.2105 \text{ CaO} - 0.781298 \text{ Na}_2\text{CO}_3 + 0.0369687 \text{ CaO}^2 + 0.0051667 \text{ CaO} * \text{Na}_2\text{CO}_3 + 0.00128 \text{ Na}_2\text{CO}_3^2$$

Where $\hat{Y}_{Mg.H.}$ = percent removal of magnesium hardness.

Note: These equations are applicable within limited range of CaO and Na₂CO₃ doses.

From the previous analysis of T.H. removal, it was noticed that CaO dose was very highly significant in split treatment and that Na₂CO₃ dose was highly significant in split treatment, see table (VII). This can be explained by the following:

First, in split treatment, the added extra lime in the 1st stage raises the pH above 10.6. That pH is optimum for Mg.H. removal. Second, the bypass flow in which the CO₂ and bicarbonate alkalinity stabilize water and lower the pH to the limit which is optimum for the removal of Ca.H. While in the one stage treatment, it is difficult to maintain the optimum pH of Ca.H. and Mg.H. removal in the same unit at the same time.

From the previous analysis of Ca.H. removal, it was noticed that CaO dose was highly significant in split treatment and that Na₂CO₃ dose was very highly significant in split treatment, see table (VII). This can be explained by the following:

In two stage split treatment, the pH in the 2nd stage is optimum for Ca.H. removal. Therefore, it will be a complete stage for Ca.H. removal.

From the previous analysis of Mg.H. removal, it was noticed that, CaO dose was highly significant in one stage treatment and that Na₂CO₃ dose was non-significant, see table (VII). This can be explained by the following:

In one stage treatment, all water quantity is treated in one unit, the added CaO dose raises the pH above 10.6. That pH is optimum for Mg.H. removal. While in two stage split treatment, only a portion of the water is treated in the first stage reaching the optimum conditions for Mg.H. removal. In the 2nd stage, the untreated bypass flow is mixed with the effluent from the 1st stage and that lower the pH below 10.6 which is not optimum for Mg.H. removal (in the second stage).

Using the path of steepest ascent, the best CaO/Na₂CO₃ dose combination was identified for each method (tables VIII, IX and X) for percent removal of T.H., Ca.H., and Mg.H., respectively. Then the expected percent removal was estimated for the split treatment method using the doses obtained for the one stage treatment.

From table (VIII), the CaO/Na₂CO₃ ratio 250 / 40.15 gives a total hardness removal percent of 51.64 in one stage while the same doses combination gives 58.33 percent removal in the split treatment.

From table (IX) the CaO/Na₂CO₃ ratio 209.5/136.19 gives calcium hardness percent removal of ≈ 100 in split treatment while the same doses combination gives 21.63 percent removal in one stage treatment.

From table (X), the CaO / Na₂CO₃ ratio 250/34.18 gives magnesium hardness percent removal of 26.53 in one stage while the same doses combination gives 46.64 percent removal in the split treatment (almost doubling the removal efficiency).

Therefore, in the water intake of El-Tabia industrial complex the split treatment method gave higher removal efficiency with less doses either in calcium oxide or sodium carbonate, and hence will reduce the operating costs. In addition, less sludge will be produced which result in reducing handling costs.

CONCLUSIONS & RECOMMENDATIONS

Rakta canal in Alexandria receives pollution from point sources domestic and industrial as well as non-point agricultural sources. The sanitary survey of Rakta canal demonstrates the presence of the following sources of pollution:

- 1- Excessive use of fertilizers and chemicals by farmers.
- 2- The huge garbage dump sites in the area between Rakta canal and Abu Qir drain in several villages and rural communities, the most important of which are Batanuni and El-Arba' Ezab villages.
- 3- A Chicken farm before the distribution well where considerable organic wastes are discharged directly into the canal.
- 4- The wastes from Ali Baba gum factory as synthetic detergents and food additives.
- 5- Direct discharge of wastes from Dr Abd ElWahab village and small-Scale industrial sources such as mechanical workshops located close to the canal.
- 6- Refuse that are disposed along the stretch of the canal.
- 7- Different pollution sources discharged or dumped intermittently into the canal such as dead animals and the domestic wastes produced from human activities such as cleaning clothes and utensils.
- 8- Withdrawing water from the Rakta canal by farmer in agricultural areas, reducing the quantity and the flow of its water, affecting the self purification capacity of the canal, and affecting the intakes of the water treatment plants in the El-Tabia industrial complex.
- 9- Floating plants create problems by clogging the screens and affect the rate of flow of raw water into the industrial water treatment plants.

The study recommends the following remedial measures to improve the quality of water in this important canal:-

- 1- Conducting awareness campaigns for the farmers concern the proper use of fertilizers and agrochemicals for various crops grown in the region as well as implementing an integrated management system.
- 2- Ban garbage dumping from sites close to the bank of the Rakta canal
- 3- Installing suitable rural sanitation systems to serve villages along the Rakta canal, specially in Nashat

Basha, Dr- Abd ElWahab, and El Hag Mohamed villages (Ezbas).

- 4- Relocate the workshops close to the banks of the Rakta canal either in Dr-Abd ElWahab village (Ezba) or in El-Hag Mohamed village (Ezba) to other areas to prevent discharge of toxic effluents to the canal.
- 5- Remove the floating plants with mechanical means along the Rakta canal.
- 6- Strengthening communication and coordination between the users of the Rakta canal, namely Rakta company, the National paper company, Abu Qir fertilizers company, and Abu Qir thermal power station to implement a strategic plan containing a continuous monitoring scheme to protect the quality of this vital industrial water intake. In addition, to provide an early warning in case of accidental spills or massive pollution which may disrupt normal operation of the strategic industries and facilities which rely on the canal for their water intake.
- 7- Furthermore, successful strategies for protection of Rakta canal must promote coordination between complement ministries [Ministry of Public Works and Water Resources, Ministry of Industry, and Ministry of Health] and the Egyptian Environmental Affairs Agency (EEAA).
- 8- For Rakta canal water, split treatment is more favourable than the one stage treatment for hardness removal. The split treatment method gives higher hardness removal efficiency with less doses either in calcium oxide or sodium carbonate, and hence reduce operating costs. In addition, less sludge will be produced which results in reducing handling costs.

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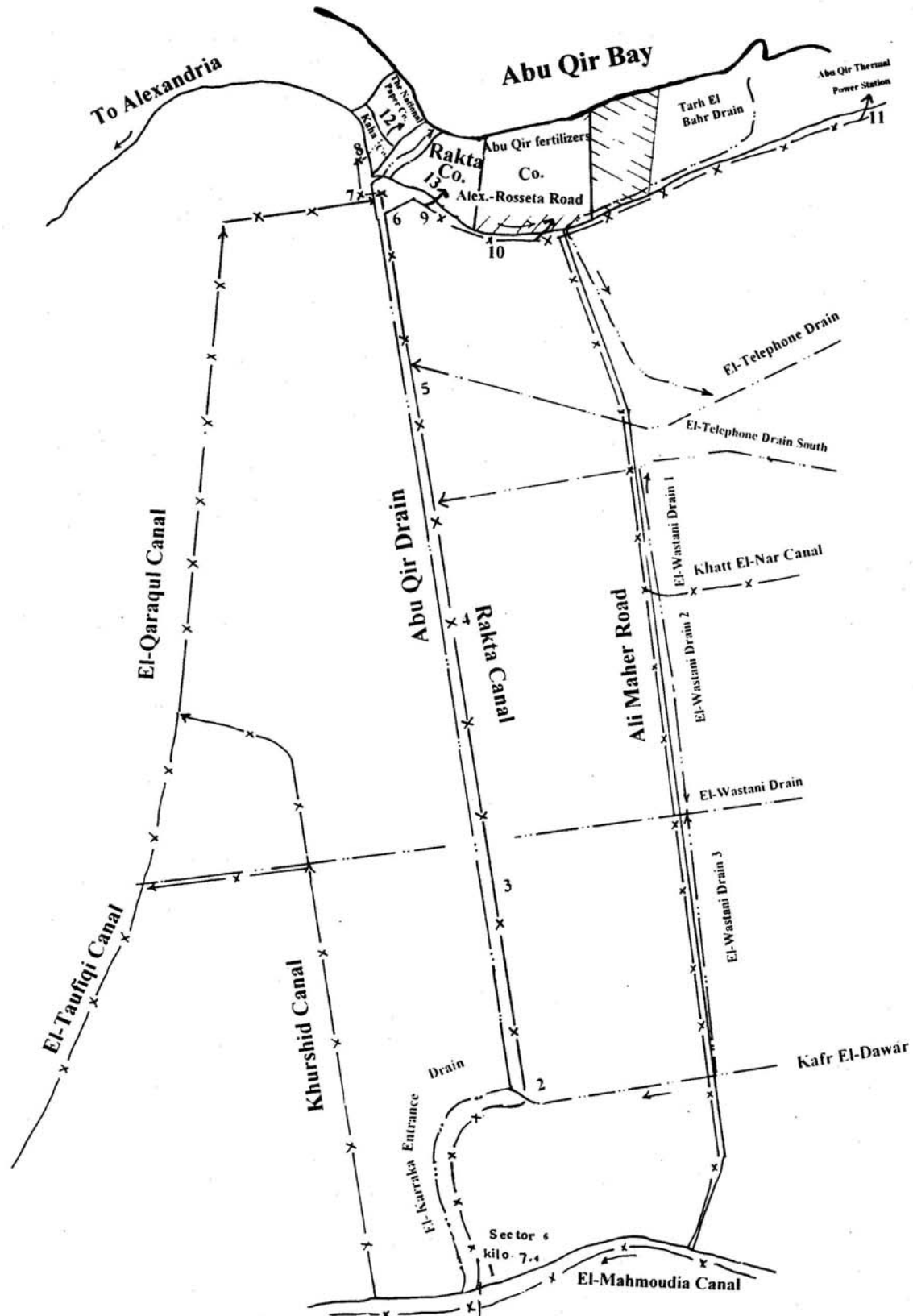


Figure (1): Rakta canal and sampling locations

Table (I) : Mean, standard deviation and range values of the physical and chemical analysis of Rakta Canal at different sampling locations, during surveyed months

(Data expressed in mg/l unless otherwise expressed)

Location Parameter		1	2	3	4	5	6	7	8	9	10	11	Total	F ratio	LSD
Temp	$\bar{X} \pm SD$	22.4±4	22.3±4	22.3±4	22.3±4	22.8±4.4	23±4.4	22.8±4.8	22.5±4.5	23±4.4	22.1±4.5	22.1±4.5	22.6±3.9	193.23	0.85
°C	R	19.5-29.5	19.5-29.5	19.5-29.5	19.5-29.5	19.5-29.5	19.5-30	19.0-30	19.5-30	19.5-30	19.5-29.5	20-31	Range (19-31)		
pH	R	7.3-7.8	7.3-7.7	7.4-7.8	7.5-7.7	7.5-7.7	7.4-7.7	7.3-7.7	7.3-7.7	7.3-7.7	7.3-7.7	7.4-8.1	Range (7.3-8.1)		
Turb.	$\bar{X} \pm SD$	6.3±2.8	7.4±3.1	7.3±2.8	5.2±1.7	5.0±1.2	5.5±2.0	6.6±4.0	5.1±1.5	5.1±2.2	8.4±5.7	7.3±3.4	6.3±3.0	8.04	2.03
N T U	R	1.8-9	2-10	1.9-9.9	2.5-7.2	3.1-6.3	2.1-7	1.8-12	2-6	2-7	2.5-19	2.4-11	307±129	4.55	97.7*
T D S	$\bar{X} \pm SD$	268±80	270±82	278±99	441±339	295±69	290±92	290±85	295±82	303±97	298±100	322±82			
	R	170-380	183-390	115-390	200-1122	209-380	148-376	152-377	159-360	152-404	160-404	171-404	520±53	39.9	22.5
Cond.	$\bar{X} \pm SD$	508±80	510±50	518±57	866±60	529±47	502±56	522±53	515±62	538±47	526±48	544±47			
mS/m	R	392-620	438-586	407-570	408-580	449-583	427-560	436-568	399-570	446-573	450-577	450-564	1.8±0.8	63.3	0.3
NO ₃	$\bar{X} \pm SD$	1.6±0.9	1.7±0.8	1.9±0.9	1.9±0.9	1.8±0.9	1.8±0.8	2.1±1.0	1.9±0.8	2.1±1.0	1.8±0.9	1.6±1.0			
	R	0.9-2.7	1.1-2.7	1.3-3.1	1.1-3.1	1.1-3.1	1.1-2.9	0.7-3.1	0.9-2.9	0.7-3.1	0.9-3.1	0.7-3.1	5.9±0.7	9.13	0.47*
DO	$\bar{X} \pm SD$	6.0±0.7	5.9±0.7	5.7±0.9	5.9±0.4	6.0±0.5	5.2±0.5	5.0±0.6	4.9±0.3	5.0±0.6	5.0±0.7	5.0±1.4			
	R	4.6-6.5	4.6-6.4	4.0-6.4	5-6.2	5.2-6.7	5.6-7.0	4.8-6.5	5-5.6	5-6.6	4.8-7	4-7.6	27.2±15.4	40.8	0.65
B O D	$\bar{X} \pm SD$	24.3±15.2	20.6±6	24.5±15.2	24.6±15.6	24.4±15.2	27.8±18	28.6±16.4	31.9±14.4	28.8±19.2	37.1±16.4	29.7±18.4			
	R	23.7-26	16-25.3	23.2-26	23.5-26	23.2-26	27.4-28	26.7-29.5	30.9-33.1	28-29.5	36.6-37.9	28.8-31.5	38±30	3.57	23.5*
C O D	$\bar{X} \pm SD$	29.2±24.9	25±13.7	29.8±12.2	29.8±6.5	28.7±42.9	40.2±42.9	34.6±17.4	38.8±30.5	58.3±58.1	61.8±32.2	47.7±30.9			
	R	18-80	18-53	20-53	19-35	10-60	10-125	10-57	10-90	10-140	35-106	18-106	57±7.6	221.2	1.54
Cl	$\bar{X} \pm SD$	56.8±8.5	56.3±8.9	56±9.3	57±8.2	57.3±9.1	57±8.1	57.0±7.6	57±8.2	57.7±8.2	58.3±7.1	59.5±7.0			
	R	44-66	44-66	44-68	47-68	47-68	48-68	48-68	46-68	50-70	51-70	52-70	209±11	44.4	4.69
Alk	$\bar{X} \pm SD$	208±16	208±12	210±13	209±10	208±12	207±14	215±14	208±12	207±10	208±10	208±12			
	R	180-220	190-220	190-220	190-220	190-220	190-230	190-230	190-220	190-220	190-220	190-220	209±23	16.46	13.5
TH	$\bar{X} \pm SD$	207±24	202±21	208±26	203±24	216±25	218±38	206±17	204±16	217±34	208±20	205±17			
	R	168-232	174-228	176-248	176-225	184-250	184-290	180-220	180-224	188-280	182-230	184-224	116±13	38.9	5.5
Ca H	$\bar{X} \pm SD$	113±13	118±12	115±15	110±15	116±12	118±13	118±15	116±12	120±18	118±14	114±17			
	R	100-136	100-136	100-140	100-116	100-136	104-140	100-142	100-132	104-152	104-140	92-138	93±22	8.55	14.8
Mg H	$\bar{X} \pm SD$	94±17	84±15	93±13	93±23	100±23	100±41	87±17	88±14	97±35	91±21	91±18			
	R	64-116	62-104	72-108	66-115	72-138	72-178	68-116	68-104	68-164	68-118	72-124	2.1±1.0	98.9	0.29
PO ₄	$\bar{X} \pm SD$	2.1±1.1	2.1±1.1	2.4±1.0	2.2±1.1	2.4±1.1	2.1±0.9	2.1±1.1	1.7±0.9	2.1±1.0	1.8±1.2	1.8±1.1			
	R	0.8-3.3	0.8-3.5	1.2-3.7	0.6-3.6	0.9-3.7	1.0-3.5	0.7-3.7	0.8-3.1	0.8-3.3	0.8-3.5	0.5-3.3	55±20	18.19	11.3*
SO ₄	$\bar{X} \pm SD$	49.2±10.2	48.3±17.2	46.7±18.3	49.2±16.3	53.3±20.2	55.8±23.3	62.5±16.4	71.7±21.6	55.8±20.8	58.3±27	54.2±29.2			
	R	35-65	35-80	30-70	35-70	35-80	30-90	35-80	45-105	30-85	30-100	20-100	9.3±5.9	4.6	4.4*
SiO ₂	$\bar{X} \pm SD$	7.7±4.8	9.0±4.3	15.7±14.8	8.4±4.1	8.7±4.2	9.0±4.2	9.0±4.3	9.0±4.0	9.4±3.9	8.9±3.8	7.3±3.0			
	R	3-15	4.3-16	5-45	4.3-15.5	4-15.6	3.8-16	4.8-16	4.7-16	4.5-15	5.1-15	3.8-11			

Table (II) : Mean, standard deviation and range values of the physical and chemical analysis of Rakta Canal at different surveyed months

Month Parameter		October	November	December	January	February	March	Total	F ratio	LSD
Temp °C	$\bar{X} \pm SD$	29.8±0.5	24.9±2.3	19.5±0.22	19.5±0.22	19.5±0.22	22.4±0.4	22.6±3.9	0.04	4.9*
	R	29.5-31	24-27	19.5-20	19.5-20	19.5-20	22-23	Range (19.5-31)		
pH	$\bar{X} \pm SD$	7.5-7.6	7.4-8.1	7.3-7.7	7.4-7.6	7.3-7.6	7.3-7.6	Range (7.3-8.1)		
	R	7.5-7.6	7.4-8.1	7.3-7.7	7.4-7.6	7.3-7.6	7.3-7.6			
Turb. N T U	$\bar{X} \pm SD$	2.3±0.4	6.1±2.0	7.5±3.0	7.1±1.5	7.0±1.4	7.6±4.1	6.3±3	0.97	3.4*
	R	3.1-1.8	4.4-11	2-12	5-9.5	5-9.5	4-19			
T D S	$\bar{X} \pm SD$	315±274	339±30	168±30	292±23	376±9	349±35	307±129	0.74	15.23*
	R	170-1122	299-382	115-228	263-309	360-390	300-404			
Cond. mS/m	$\bar{X} \pm SD$	561±9	541±19	526±37	500±31	561±31	429±22	520±53	0.24	64.7*
	R	550-577	520-585	488-620	427-530	496-586	392-450			
NO ₃	$\bar{X} \pm SD$	1.5±0.7	1.3±0.3	1.4±0.3	1.0±0.2	3.0±0.2	2.8±0.1	1.8±0.8	0.21	1.0*
	R	0.7-2.8	1.1-2.2	1.1-1.8	0.7-1.3	2.7-3.1	2.7-2.9			
DO	$\bar{X} \pm SD$	4.9±0.5	5.9±0.4	5.9±0.3	5.9±0.8	6.1±0.5	6.4±0.7	5.9±0.7	0.63	0.9*
	R	4.0-5.6	5.0-6.2	5.6-6.6	4.0-7.0	5.4-7.0	5.0-7.6			
B O D	$\bar{X} \pm SD$	26.8±21.2	27.8±19	26.1±17	28.3±17	27±14	27.2±14	26.2±15	0.32	1.9*
	R	22-36.9	16-37.9	20-36.6	25.3-37.8	19-36.8	23.1-36.8			
Temp	$\bar{X} \pm SD$	29.0±14	61±15	26±12	46±39	44±23	19±12	38±30	1.18	34.4*
	R	18-53	20-125	18-53	20-140	20-90	10-46			
Cl	$\bar{X} \pm SD$	52±2.3	52±12	62±1.7	68±1.4	62±0.6	47±2.8	57±7.6	0.09	9.5*
	R	48-56	50-53	60-64	66-70	62-64	44-52			
Alk	$\bar{X} \pm SD$	221±3	244±4	212±8	204±7	216±7	190±4	209±11	0.25	14.1*
	R	220-230	205-220	200-220	200-220	210-230	180-195			
TH	$\bar{X} \pm SD$	223±36	213±7	224±4	188±2	223±40	180±7	209±23	0.32	28.7*
	R	180-230	204-224	220-232	184-190	212-248	168-188			
Ca H	$\bar{X} \pm SD$	114±3	106±7	124±6	106±6	137±10	110±4	116±13	0.27	15.7*
	R	112-120	92-116	110-128	100-112	136-152	104-114			
Mg H	$\bar{X} \pm SD$	109±36	107±9	100±9	82±8	86±15	70±6	93±22	0.30	26.9*
	R	70-178	88-124	92-116	72-90	68-115	62-84			
PO ₄	$\bar{X} \pm SD$	0.9±0.2	2.4±0.4	2.2±0.5	4.0±0.3	2.8±0.3	3.5±0.2	2.1±1.0	0.25	1.2*
	R	0.6-1.2	1-2.5	0.8-2.7	0.5-1.3	2.5-3.3	3.1-3.7			
SO ₄	$\bar{X} \pm SD$	70±7	68±23	73±15	36±4	38±14	45±9	55±20	0.75	23.9*
	R	55-80	40-405	55-100	30-45	20-65	35-55			
SiO ₂	$\bar{X} \pm SD$	15±17	8.8±1.4	108±1.1	8.0±12.3	7.5±1.7	54±1.4	9.3±5.9	0.84	6.8*
	R	10-16	7-11.4	8.4-11.8	3.6-45	3-10	4-7.6			

Table (III): Mean, standard deviation, differences and paired t of water quality before and after the water treatment plant in Rakta Co. (mg/l)

Parameter	Before $\bar{X} \pm SD$	After $\bar{X} \pm SD$	Difference after- before	Paired t
pH (range)	7.3-7.7	7.5-7.8	-	1.35
Turbidity NTU	5.1 \pm 2.2	0.97 \pm 0.40	4.13	5.41**
TDS	303 \pm 97	298 \pm 102	5.0	0.81
Conductivity (mS/cm)	528 \pm 47	519 \pm 71	9.0	0.7
NO $\bar{3}$	2.1 \pm 1.0	1.9 \pm 0.8	0.2	0.91
DO	5.9 \pm 0.6	7.8 \pm 1.0	1.9	5.31*
BOD	28.8 \pm 19.2	22.7 \pm 15.9	6.1	2.27
COD	58 \pm 58	47 \pm 35	11.0	0.56
Cl $^-$	58 \pm 8	57 \pm 8	1.0	1.0
Alkalinity	207 \pm 10	207 \pm 12	0.0	0.0
TH	217 \pm 34	207 \pm 17	10.0	1.0
CaH	120 \pm 18	116 \pm 11	4.0	1.27
MgH	97 \pm 35	91 \pm 18	6.0	0.65
PO $_4$	2.1 \pm 1.0	1.5 \pm 0.9	0.6	2.77*
SO $_4$	56 \pm 21	56 \pm 15	0.0	1.0
Si O $_2$	9.4 \pm 4.0	9.0 \pm 3.4	0.4	1.61

Table (IV): Mean, standard deviation, differences and paired t of water quality before and after the water treatment plant in the National Paper Co. (mg/l)

Parameter	Before $\bar{X} \pm SD$	After $\bar{X} \pm SD$	Difference after- before	Paired t
pH (range)	7.3-7.7	7.1-7.7	-	1.22
Turbidity NTU	5.1 \pm 1.5	2.1 \pm 0.9	3.0	6.7***
TDS	295 \pm 82	294 \pm 84	1.0	0.17
Conductivity (mS/cm)	520 \pm 66	493 \pm 57	27.0	2.1
NO $\bar{3}$	1.9 \pm 0.8	1.7 \pm 0.9	0.2	1.39
DO	4.9 \pm 0.3	7.6 \pm 1.0	2.7	5.14*
BOD	31.9 \pm 14.4	31.1 \pm 22.3	0.8	0.5
COD	39 \pm 30	35 \pm 28	4.0	1.24
Cl $^-$	57 \pm 8	55 \pm 7	2.0	1.23
Alkalinity	208 \pm 12	199 \pm 18	9.0	2.19
TH	204 \pm 16	203 \pm 20	1.0	0.33
CaH	116 \pm 12	114 \pm 7	2.0	0.55
MgH	88 \pm 14	89 \pm 14	1.0	0.55
PO $_4$	1.7 \pm 0.9	0.7 \pm 0.2	1.0	3.06*
SO $_4$	72 \pm 22	68 \pm 159	4.0	0.53
Si O $_2$	8.9 \pm 4.0	6.5 \pm 3.1	2.4	3.05*

* Significant difference p < 0.05

** Very significant difference p < 0.01

*** Very highly significant difference p < 0.001

Table (V): Jar test results of hardness removal using different combinations of CaO and Na₂CO₃ doses (one stage)

Parameter Doses		T.H			Ca.H			Mg.H		
		Samples S _n								
CaO	Na ₂ CO ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
0	0	208	224	222	128	128	112	80	96	110
260	55	110	124	112	47	58	30	63	66	82
190	55	115	116	130	45	42	38	70	74	92
225	35	107	120	110	40	36	34	67	84	76
175	35	165	222	132	89	128	44	76	94	88
225	7	146	152	160	78	66	76	68	86	84
260	15	101	98	118	42	44	32	59	54	86
90	15	142	112	192	71	36	88	71	76	104
275	35	100	86	128	41	38	36	59	48	92
225	65	108	104	126	35	24	34	73	80	92

n = raw water sample number

S₃ was used in the analysis test**Table (VI): Jar test results of hardness removal using different combinations of CaO and Na₂CO₃ doses (split treatment)**

Parameter Doses		T.H			Ca.H			Mg.H		
		Samples S _n								
CaO	Na ₂ CO ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
0	0	212	210	208	108	108	110	104	102	98
200	55	138	100	116	36	46	30	102	54	86
120	55	142	134	158	38	40	60	104	94	98
160	35	142	140	156	38	46	60	104	94	96
103	35	150	146	164	46	60	68	104	86	96
160	7	164	152	156	60	56	58	104	96	98
200	15	140	136	150	50	40	52	90	96	98
120	15	150	152	166	48	64	68	102	88	98
216	35	124	88	134	44	40	40	80	48	94
160	63	130	120	132	34	32	40	96	88	92

n = raw water sample number

S₃ was used in the analysis test

Table (VIII) : Results of steepest ascent for T.H. removal percent

O N E S T A G E			S P L I T		
CaO Dose	Na ₂ CO ₃ Dose	TH Removal Percent	CaO Dose	Na ₂ CO ₃ Dose	TH Removal Percent
225.0	36.00	47.96	159.5	35.00	30.42
230.0	37.41	49.25	169.5	38.81	32.97
235.0	38.67	50.23	179.5	42.26	35.91
240.0	39.69	50.94	189.5	45.45	39.26
245.0	40.31	51.39	199.5	48.45	43.02
250.0	40.15	51.54	209.5	51.32	47.19

Expected percent removal if CaO and Na₂CO₃ one stage doses were used in the Split treat =58.33

The dose combination of 230 mg CaO + 51 mg Na₂CO₃ gives removal of 54.51%

The dose combination of 220 mg CaO + 52 mg Na₂CO₃ gives removal of 51.11% of TH by the Split method

Table (IX) : Results of steepest ascent for Ca.H. removal percent

O N E S T A G E			S P L I T		
CaO Dose	Na ₂ CO ₃ Dose	CaH Removal Percent	CaO Dose	Na ₂ CO ₃ Dose	CaH Removal Percent
225.0	36.00	68.39	159.5	35.00	55.84
230.0	38.62	70.31	169.5	41.72	59.27
235.0	41.71	71.65	179.5	49.86	63.11
240.0	49.83	72.41	189.5	60.46	67.83
245.0	50.77	71.96	199.5	76.63	74.90
250.0	52.03	71.08	209.5	136.19	100.00*

* Actual value=105.00 rounded to 100

Expected percent removal if CaO and Na₂CO₃ Split treat doses were used in the one stage =21.63

The dose combination of 140 mg CaO + 30 mg Na₂CO₃ gives removal of 51.48% of CaH by the Split method

Table (X) : Results of steepest ascent for Mg.H. removal percent

O N E S T A G E			S P L I T		
CaO Dose	Na ₂ CO ₃ Dose	MgH Removal Percent	CaO Dose	Na ₂ CO ₃ Dose	MgH Removal Percent
225.0	36.00	21.03	159.5	35.00	3.31
230.0	35.82	22.07	169.5	37.06	5.56
235.0	35.53	23.14	179.5	39.99	8.74
240.0	35.16	24.24	189.5	40.85	12.86
245.0	34.70	25.37	199.5	42.68	17.89
250.0	34.18	26.53	209.5	44.48	23.86

Expected percent removal if CaO and Na₂CO₃ one stage doses were used in the Split treat =46.64

The dose combination of 255 mg CaO + 35 mg Na₂CO₃ gives removal of 51.32% of MgH by the Split method