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# PERFORMANCE OF FILTRATION SYSTEMS TO ENHANCE TREATED WATER QUALITY

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## ABSTRACT

The aim of this paper is to evaluate the performance of three surface water treatment plants using different filtration technologies. The performance evaluation was based on variations in turbidity, total dissolved solids “TDS” and total solids “TS” as well as micro-organisms counts in raw and filtered water in addition to an economic comparison between the studied treatment processes with different filtration systems following an evaluation of collected data along four years from existing water treatment plants “WTPs” in Menofia Governorate. The main conclusions of results revealed similar performance in removal of turbidity, microorganisms and TS concentration through various filtration systems. Direct filtration system with a declining rate was considered the most economic in operation. The results also indicated that conventional filtration system stands in an intermediate position in terms of economic comparisons. Although pressurized compact filtration system recorded efficiencies same as other systems in terms of removal of turbidity and microorganisms, the system was the least favored in economical comparisons under the studied conditions “e.g. flow, water quality, consumables”.

KEYWORDS: Filtration systems, turbidity, total solids, microorganisms, economic comparisons.

## 1. INTRODUCTION

Access to safe drinking water is important as a health and development contributor at the national, regional and local levels. In some regions, it has been shown that investments in water supply can yield a net economic benefit since the

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reductions in health care costs adverse and health effects outweigh the costs of undertaking the interventions. Indeed, a continuous effort should be made to maintain drinking-water quality at the highest possible level [1]. Filtration is a process commonly used for the removal of objectionable matter through water treatment process.

Rapid gravity filters with granular media is the most widely used filtration process in drinking water treatment resulting in a high rate of fine solids separation. The effective part of rapid gravity filter responsible of solids removal is usually the sand filtration medium. When fine sand is used, the collection of solids during filtration, and hence the buildup of head loss, tends to be within the top layers of the sand. In contrast, with coarser sands the solids penetrate to a greater depth and the lower layers of the sand bed are then called upon to do some of the works of solid removal [2]. These impurities consist of suspended particles “fine silts and clays”, biological matter “bacteria, plankton, spores, cysts or other matter” and flocs of suspended solids. [3].

In Menofia Governorate - Egypt, several filtration systems are used for solids separation such as rapid gravity filtration, direct filtration with a declining rate and pressurized filters. The technical and economical comparisons between these filtration systems based on long term monitoring aims at highlighting their performance for future guidance when constructing new water treatment plants using filtration systems suitable to Menofia Governorate. This paper thus evaluates and compares performance of different water filtration systems used in Menofia Governorate namely conventional gravity filtration, direct filtration and pressurized filtration regarding their efficiencies, average required areas, cost of construction and operation as to identify the optimal and appropriate filtration systems currently in use.

## 2. MATERIALS AND METHODS

Data were collected from different filtration systems currently in operation in Menofia Governorate with a full description of each studied water treatment plant aiming to the identification of the optimal filtration system currently in use. This investigation also addressed three main issues as follows: statistical results showing turbidity variations in both raw water and treated water, "ii" amount of microorganisms and total solids in raw and treated water and "iii" system requirements in terms of electrical power, required land space, labor salaries, monthly consumption of chlorine and alum, washing frequency and construction cost.

Data on raw and treated water quality were made available by Water and Wastewater Co. of Menofia Governorate; these were monthly collected along four years including data on turbidity, TDS & total solids as well as microorganisms count. The average removal efficiencies of these parameters were assessed for the three different studied filtration systems "gravity sand filtration, direct filtration and pressurized filters". Moreover, these different filtration processes were economically evaluated as to cover both technical and financial aspects in the comparison.

## 2.1 Study Area

Three filtration systems in existing WTPs were studied as described below:

1) Traditional filtration system which in Main Shebin El Kom WTP that includes as shown in flow line diagram in Fig. 1 screens, intake, 4 clari-flocculators "26 m diameter - 2200 $m^3$ volume", 10 filters "each 3.9 m width, 16.7 m length, 80 cm depth of sand of size 0.8:1.6 mm and 30cm depth of gravel", the design capacity of the plant is 69000 $m^3$/day "800 l/s".

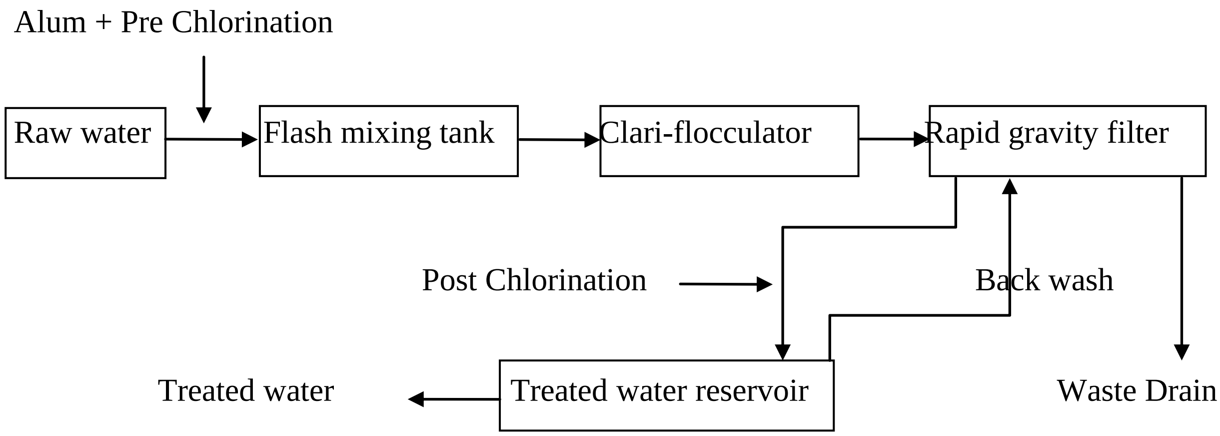


Fig. 1. Flow line diagram of Main Shebin El Kom water treatment plant.

2) Direct gravity filtration system with a declining rate in Mit Mosa WTP [4] that includes as shown in Fig. 2 components of direct gravity filtration system such as raw water pumps, flocculation system "with no following sedimentation process", deep bed sand filters, washing system and compressed air equipment. The direct filtration is applied through a fine aggregate layer 2-4 mm and 110-125 cm depth, and the design capacity of the plant is 120 l/s.

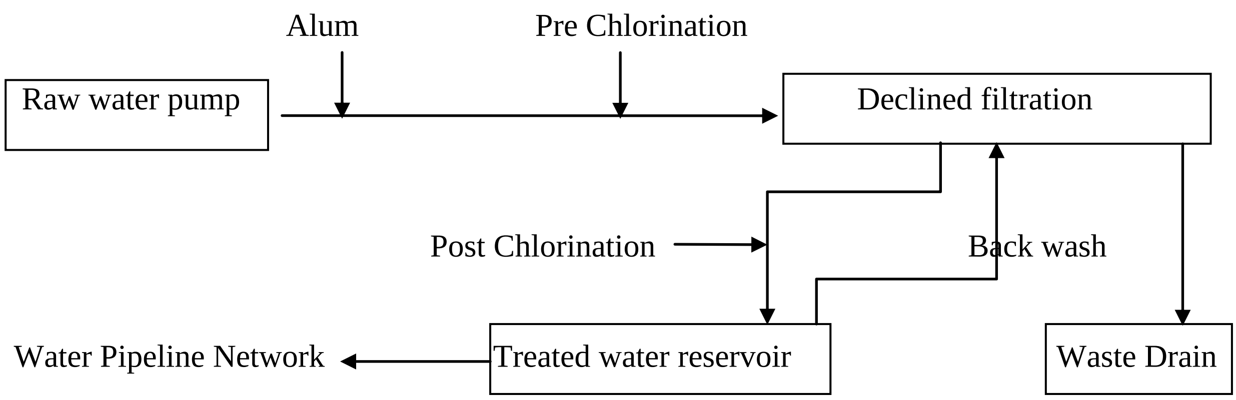


Fig. 2. Flow line diagram of Mit Mosa water treatment plant.

3) Pressurized filter system process used in El Dalatoun WTP "Fig. 3" has the filtration medium contained in 3 vertical closed steel cylinders "1.8 m diameter and 2.5 m height from which 120 cm of sand and 30 cm of gravel" receive water through pressure pumps. The design capacity of the plant is 30 l/s.

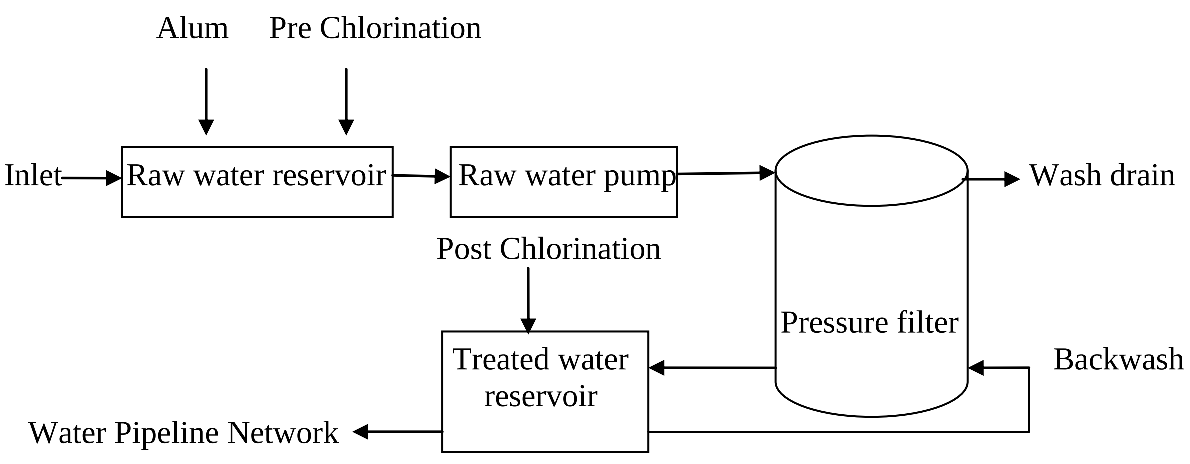


Fig. 3. Flow line diagram of El Dalatoun water plant treatment plant.

## 2.2 Comparison parameters

Different filters were compared by measuring the change in filtered water quality through measure of Turbidity [5], TDS and microorganisms count in both raw water and treated water. Economic comparison between different filtration systems considered several factors as electrical power consumption, required areas, operation and maintenance cost, consumption of chemicals "chlorine and alum", backwashing frequency as a measure of media consumption and construction cost, this is guided by value engineering as to identify function reliability at the least overall cost [6].

# 3. RESULTS AND DISCUSSIONS

Performance evaluation for the three studied filtration processes considered several operational parameters as follows:

## 3.1 Technical Evaluation

The technical evaluation considers the product water quality after filtration and compare filtration system efficiency taking into consideration raw / settled water quality. As previously mentioned, main parameters of concern are Turbidity, TDS / TD and microorganisms count. Figure 4 shows the performance of the three filtration systems for removal of turbidity from water source from 2012 to 2016.

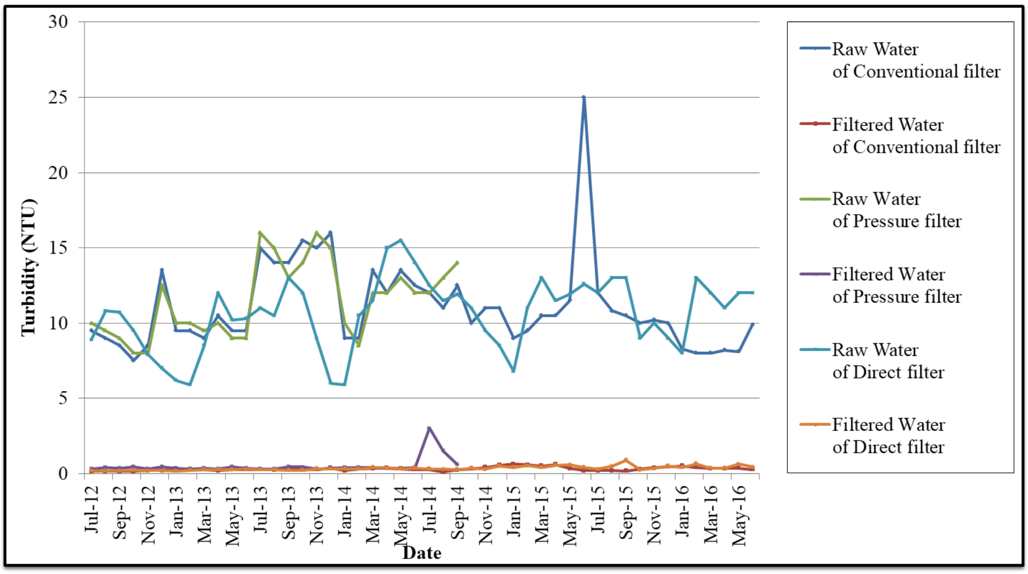


Fig. 4. Turbidity of raw and filtered water during 2012/2016

Table 1 also shows various operational parameters for the 3 different filtration processes along the period from 2012 to 2016 where removal efficiency for Shebin El Kom, Mit Mosa and El Dalatoun WTPs were 97.29%, 96.75% & 95.51% respectively.

Table1. Turbidity “NTU” in the raw and filtered water in the three system during 2012-2016.

| | Conventional filter (Shebin El Kom WTP) | | Pressure filter (El Dalatoun WTP) | | Direct filter (Mit Mosa WTP) | |
|---|---|---|---|---|---|---|
| | Raw Water | Filtered Water | Raw Water | Filtered Water | Raw Water | Filtered Water |
| Average | 11.05 | 0.30 | 11.48 | 0.52 | 10.57 | 0.34 |
| Standard Deviation | 3.00 | 0.13 | 2.46 | 0.55 | 2.34 | 0.15 |
| Range | 17.50 | 0.53 | 8.00 | 2.70 | 9.60 | 0.73 |

Since the filtration system is a solids separation system, it is not expected that much variation in Total Dissolved Solids “TDS” occurs unless there is biological activities in the filters leading to uptake of some dissolved solids. The Empty Bed Contact Time “EBCT” in such filtration systems is very small, therefore, it is expected that no distinguished variation in TDS will occur for the 3 different studied processes as shown in Fig. 5 and in Table 2.

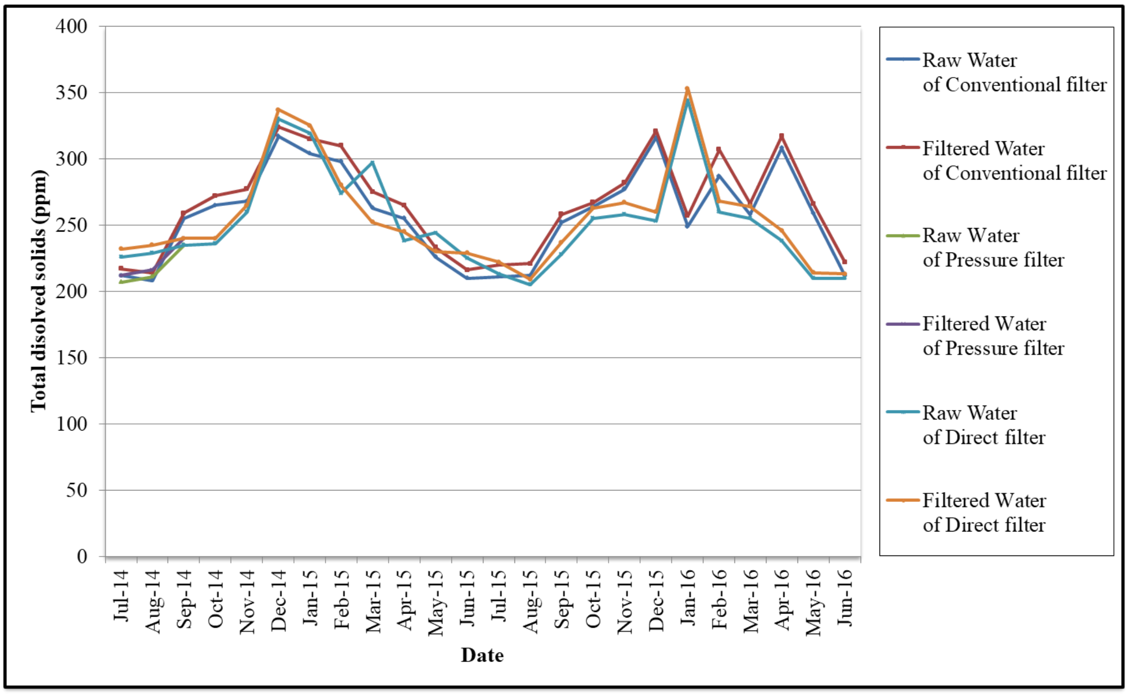


Fig. 5. TDS in raw and filtered water in the systems.

Table 2. TDS changes in studied three treatment systems during 2014-2016.

| | Conventional filter (Shebin El Kom WTP) | | Pressure filter (El Dalatoun WTP) | | Direct filter (Mit Mosa WTP) | |
|---|---|---|---|---|---|---|
| | Raw Water | Filtered Water | Raw Water | Filtered Water | Raw Water | Filtered Water |
| Average | 257.75 | 265.88 | 217.67 | 222.67 | 251.75 | 255.25 |
| Standard deviation | 35.50 | 36.40 | 15.14 | 15.14 | 37.59 | 37.46 |
| Range | 109.00 | 110.00 | 28.00 | 28.00 | 139.00 | 144.00 |

A tiny increase in TDS may be noted possibly due to the effect of pre-chlorination in destroying any microbial films opting to flourish within the filtration media and thus release of such minor amounts. Also the effect of chemicals addition as part of the process for treatment is one important factor for the consistency of such minor increase in TDS.

Microorganisms count is considerably reduced through the water treatment process though the variation of filtration process and after treated water disinfection as shown in Fig. 6 and Table 3 in order to comply with regulations for treated water.

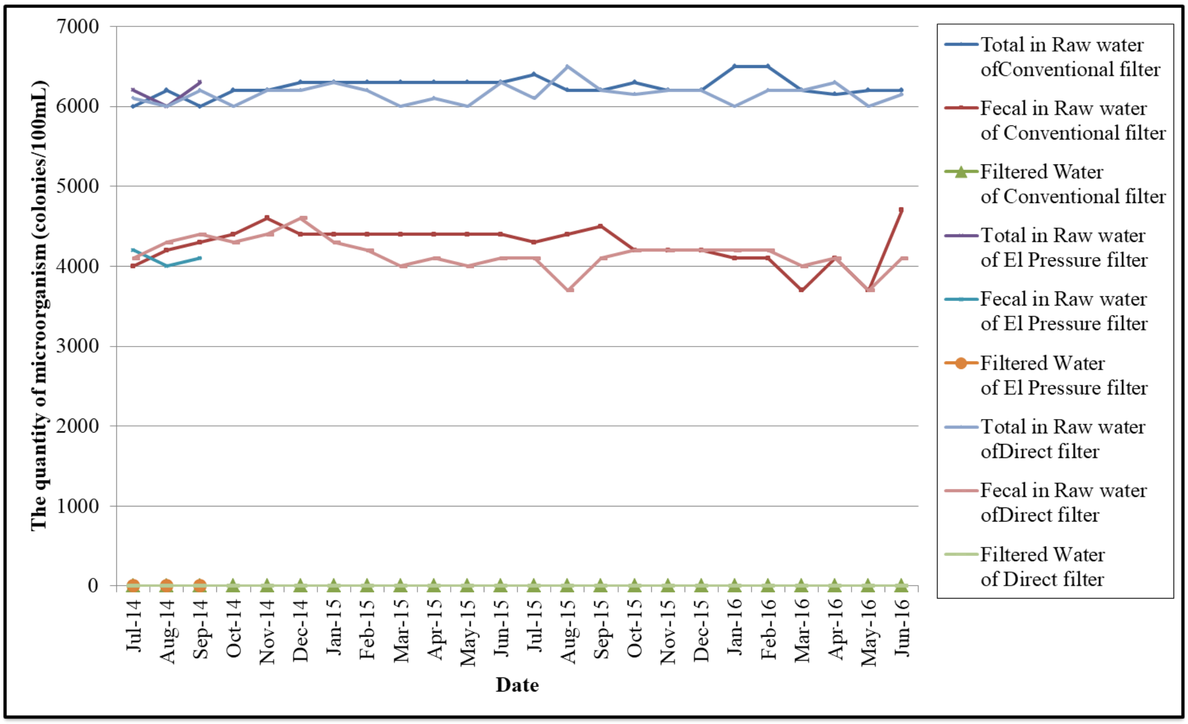


Fig. 6. Microorganisms in raw and filtered water in the system during 2014-2016.

Table 3. Microorganisms "colonies/100mL" changes in the three systems during 2014-2016.

| | Conventional filter (Shebin El Kom WTP) | | | Pressure filter (El Dalatoun WTP) | | | Direct filter (Mit Mosa WTP) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Fecal | Filtered Water | Total | Fecal | Filtered Water | Total | Fecal | Filtered Water |
| Average | 6247.92 | 4270.83 | 0.00 | 6166.67 | 4100.00 | 0.00 | 6158.33 | 4150.00 | 0.00 |
| Standard deviation | 119.31 | 240.43 | 0.00 | 152.75 | 100.00 | 0.00 | 123.94 | 197.81 | 0.00 |
| Range | 500.00 | 1000.00 | 0.00 | 300.00 | 200.00 | 0.00 | 500.00 | 900.00 | 0.00 |

It is thus important to note that the three studied water treatment plants with the different filtration processes "rapid gravity filter, direct filtration and pressurized filtration" were all successful in the removal of turbidity and microorganisms to the level complying with treated water quality criteria. This goes in accord with the long term use of these treatment processes for surface water treatment along decades. The economic study thus would provider indicators for preference in terms of cost related to various aspects of construction and operation as discussed in the following section.

## 3.2 Economic Evaluation

In order to conduct an economic comparison for the 3 different studied water treatment plants adopting three different filtration processes, main parameters concerning the various economic aspects of these plants are shown in Table 4.

Table 4. Economic comparison of maintenance and operation cost between different systems.

| | Name | Shebin El Kom | | El Dalatoun | Mit Mosa |
|---|---|---|---|---|---|
| Process of filter | | Conventional filter | | Pressure filter | Direct filter |
| Actual capacity ($m^3$/month) | | 1,500,000 | | 50,400 | 245,722 |
| Chlorine used (Kg/month) | | 45630 | | 253 | 1609 |
| Alum used (Kg/month) | | Liquid 119074 | Powder 17964 | 365 | 6732 |
| Backwashing | Filter Dimension | 16.7 × 3.9 m | | Ø 1.8 m | 7 × 4 m |
| Backwashing | No. of filter | 8+2 | | 3 | 3+1 |
| Backwashing | Surface Areas of the used filters | 521 | | 7.63 | 84 |
| Backwashing | Rate of filtertion ($m^3/m^2$/d) | 133 | | 340 | 123 |
| Backwashing | Percent of Water Wasted asFilter Backwash | 8.50% | | 10% | 15% |
| Backwashing | Working H/day | 24 | | 12 : 16 | 18 |
| Backwashing | Backwashing Frequency No. /day | 0.75 | | 3 | 2 |
| land area $m^2$ | | 40000 | | 1000 | 1200 |
| Electrical power( KWatt/ month) | | 353025.5 | | 19750 | 54050 |
| Staff salaries (pound/ month) | | 193430.2 | | 31210.4 | 65887.8 |
| Cost | Construction Current value (Million Pound). | 250 | | 8 | 25 |
| Cost | Actual capacity (L/s) | 580 | | 19.4 | 94.8 |
| Cost | Design capacity (L/s) | 800 | | 30 | 120 |
| Cost | Capacity If 24H Working (L/s) | 800 | | 30 | 120 |
| Cost | Efficienty | 100% | | 100% | 100% |
| Cost | Construction cost (Million Pound) | 250 | | 8 | 25 |

Moreover, the different aspects of comparison for consumables to produce 100 $m^3$ of filtered water are chlorine and alum consumption, backwashing frequency as a measure of media consumption, required areas, electric power consumption, monthly labor cost and construction cost. These specific parameters for the three studied water treatment plants are shown in Table 5.

Table 5. Comparison of consumed materials to produce 100 $m^3$ of filtered water.

| Name | Shebin El Kom | El Dalatoun | Mit Mosa |
|---|---|---|---|
| Process of filter | Conventional filter | Pressure filter | Direct filter |
| Chlorine used (Kg) | 3.042 | 0.502 | 0.655 |
| Alum used (Kg) | 9.136 | 0.727 | 2.740 |
| Backwashing Frequency No. /day | 0.002 | 0.179 | 0.024 |
| land area $m^2$ | 2.667 | 1.984 | 0.488 |
| Electrical power ( KWatt) | 23.535 | 39.187 | 21.996 |
| Staff salaries (pound) | 12.895 | 61.925 | 26.814 |
| Construction cost (Pound). | 16667 | 15873 | 10174 |

Pressurized filtration and direct filtration systems use less chlorine doses than conventional rapid sand filtration system; this could be attributed to the increase in microorganisms count in raw water of Shebin El Kom as shown in Table 3 and not directly related to system requirements. Moreover they are also using less doses of alum than conventional filtration system. This is due to the presence of Clari-flocculators before conventional filtration system which requires the formation of large flocs for the sedimentation process prior to the gravity sand filter system.

The economic evaluation process assigns weight for various criteria of evaluation according to its expected impact. First, the weight of the desired criteria has been extracted from Table 6 in which the mutual weight factors of each aspect of comparison against the others are presented. The raw weight for each criterion is estimated. The estimation varies from one country to another based on economic status, human resources, etc. In order to cope with a reasonable assumption for economic evaluation, two sets of factors were considered pertaining to Capital Cost “construction cost and land cost” and Operation Cost “consumables from alum and chlorine, electric power consumption, cost of operators, and extent of backwash which in turns is reflected in losses of produced water with all induced consumables herein stated". It is assumed that both construction cost and operation cost has similar importance thus assigning 50% of weight to each of them as the construction of the new facilities requires an upfront investment, while systems with considerable requirements for operation would require an investment equal to capital cost on the long run. Moreover, the five factors affecting operation cost were looked at equally while the construction cost was considered as 80% of the Capital Cost while the land area price would be assigned the remaining 20% weight of this category. Indeed these weights may vary from project to project specially with the application of new technologies "as membranes" and are thus limited to the studied case as for the weights shown in Table 6. Current implementation costs for similar projects were also taken into account during the economic evaluation.

Table 6. The Weight of each consumed materials in Percentage.

| The points of comparison | Raw Weight | Normalized Weight |
|---|---|---|
| Consumption of Chlorine | 2 | 10% |
| Consumption of Alum | 2 | 10% |
| Backwashing Frequency | 2 | 10% |
| Required Areas | 2 | 10% |
| Electrical Power Consumption | 2 | 10% |
| Staff salaries | 2 | 10% |
| Construction Cost | 8 | 40% |
| Total | 20 | 100% |

Table 7 compares the various economic parameters related to construction and operation considering them as a percent share from a total of 100% for each item of comparison where several indicators can be seen as the least area requirement as well as construction cost for direct filtration, the highest electric consumption for pressurized filtration, the highest chemicals consumption for the conventional system with gravity rapid "conventional" filters; this latter indicator was also due to higher stress on water source requiring higher use of chemicals.

Table 7. Summary of Economic Evaluation for Studied Processes.

| Process of filter | | Conventional filter | | Pressure filter | | Direct filter | |
|---|---|---|---|---|---|---|---|
| Elements of comparisons | Total consumed to filter 300 m3 in the three filteration systems | consumed to filter 100 m3 | Ranks | consumed to filter 100 m3 | Ranks | consumed to filter 100 m3 | Ranks |
| Chlorine used (Kg) | 4.199 | 3.042 | 0.72 | 0.502 | 0.12 | 0.655 | 0.16 |
| Alum used (Kg) | 12.603 | 9.136 | 0.72 | 0.727 | 0.06 | 2.740 | 0.22 |
| Backwashing Frequency No. /day | 0.204 | 0.002 | 0.01 | 0.179 | 0.87 | 0.024 | 0.12 |
| land area $m^2$ | 5.139 | 2.667 | 0.52 | 1.984 | 0.39 | 0.488 | 0.10 |
| Electrical power ( KWatt) | 84.718 | 23.535 | 0.28 | 39.187 | 0.46 | 21.996 | 0.26 |
| Staff salaries (pound) | 101.635 | 12.895 | 0.13 | 61.925 | 0.61 | 26.814 | 0.26 |
| Construction cost (Pound). | 42714 | 16667 | 0.390 | 15873 | 0.372 | 10174 | 0.238 |

Finally, the rank "percent share" of each element of economic comparison is transformed to a score based on the weight between values presented in Table 6. As the percent share of consumables and higher construction cost shown in Table 7 are considered as defects in the comparison, these are assigned negative values. The final evaluation and scoring for ranking the economic adequacy of the three studied filtration systems is reflected by the summation of the residual of percent share "100% - percent share" multiplied by the relative weight of each element of economic comparison, as presented in Table 8 where the overall sum of factors show the most favorable process, this procedure was also applied in similar comparisons [7].

Table 8. Score of Points of Comparison.

| **Process of filter** | | **Conventional filter** | | **Pressure filter** | | **Direct filter** | |
|---|---|---|---|---|---|---|---|
| Elements of comparisons | Normalized Weight | Ranks | Score | Ranks | Score | Ranks | Score |
| Chlorine used (Kg) | 10% | -0.72 | 0.028 | -0.12 | 0.088 | -0.16 | 0.084 |
| Alum used (Kg) | 10% | -0.72 | 0.028 | -0.06 | 0.094 | -0.22 | 0.078 |
| Backwashing Frequency No. /day | 10% | -0.01 | 0.099 | -0.87 | 0.013 | -0.12 | 0.088 |
| land area $m^2$ | 10% | -0.519 | 0.048 | -0.386 | 0.061 | -0.095 | 0.090 |
| Electrical power ( KWatt) | 10% | -0.28 | 0.072 | -0.46 | 0.054 | -0.26 | 0.074 |
| Staff salaries (pound) | 10% | -0.13 | 0.087 | -0.61 | 0.039 | -0.26 | 0.074 |
| Construction cost (Million Pound). | 40% | -0.390 | 0.244 | -0.372 | 0.251 | -0.238 | 0.305 |
| Total score | 100% | | 0.606 | | 0.600 | | 0.794 |

Based on the above table, direct filtration process was the most favorable process from economic aspects followed by conventional gravity filtration while the pressurized filtration came third. A sensitivity analysis was conducted by further reducing and increasing the effect “weights” of construction cost giving alternative effects of operation cost to be maximum and minimum consequently; the results remained with the same rank though the difference in collective scores which further highlights the importance of direct filtration process for surface water where raw water quality enables such application.

Following the above mentioned technical and economic comparisons of the studied three filtration systems currently in use in Menofia Governorate, the results showed the high efficiency of all studied systems turbidity and microorganisms’ removal, total dissolved solids normally remains unchanged due to the type of treatment process applied with minor increase due the use of chemicals within the plants. The economic evaluation and its sensitivity analysis showed a better ranking for direct filtration system still with an acceptable performance of gravity “conventional” filtration followed by pressurized filtration which has more operational cost requirements under the studied conditions.

## 4. CONCLUSIONS

This study provided technical and economical comparison and evaluation of three water treatment plants applying different filtration processes namely gravity “conventional” filtration or rapid sand filters, direct filtration and pressurized filtration. The technical comparison showed a high efficiency for all studied water treatment systems using various filtration processes for removal of contaminants as microorganisms as well as turbidity to the required levels. It is to note that these plants have various capacities / flows and the economic study opted to normalize the comparison factors “as chemicals and electric consumption and construction cost among others” per selected unit of produced “treated” water in order to apply economic comparisons, ranking and final evaluation that showed a higher preference of direct filtration followed by conventional filtration then pressurized filtration.

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## أداء أنظمة الترشيح لتحسين نوعية المياه المعالجة

يتناول البحث تقييم أداء تقنيات الترشيح المختلفة بمحافظة المنوفية من خلال دراسة ثلاث محطات لتنقية "معالجة" مياه الشرب من مصادر المياه السطحية تستخدم تقنيات مختلفة للترشيح هى الترشيح التقليدى بالمرشحات الرملية السريعة ونظام الترشيح المباشر والترشيح بالضغط. وتم التقييم على أساس قدرة المرشحات ونظام التنقية ككل على إزالة العكارة والكائنات الحية الدقيقة كما شملت الدراسة المقارنة الاقتصادية لكل نظام ترشيح وتقييم استهلاك الطاقة ومساحة الأرض والعمالة المُشغلة واستهلاك الكيماويات "الشبه" والكلور واستهلاك الطاقة الكهربية إضافة الى تكلفة البناء وعوامل أخرى، وأظهرت النتائج كفاءة نظم التنقية باستخدام تقنيات الترشيح المختلفة فى إزالة العكارة والكائنات الحية الدقيقة بالكفاءة المطلوبة وتوصلت الدراسة الإقتصادية إلى أن الترشيح المباشر هو الأفضل بتقييم المؤشرات الإقتصادية المختلفة حيث لا يتعارض استخدامه مع نوعية المياه الخام، يليها نظام الترشيح التقليدى ثم الترشيح بالضغط.