Physically and chemically treating sulphurous water in western of Iraq

M. Y. Khudair\textsuperscript{1*} and Y. K. Al-Hadithi\textsuperscript{2}

\textsuperscript{1}Civil Engineering, College of Engineering, University of Anbar, Ramadi, Iraq
\textsuperscript{2}Soil and water Sciences, College of Agriculture, University of Anbar, Ramadi, Iraq
* Corresponding author’s e-mail: ag.marwa.yass@uoanbar.edu.iq

Abstract. The agricultural sector in Iraq is one of the country’s most water-consuming sectors. Recent shortages of fresh water have made it necessary to utilise treated water, whether sewage water, sulphurous water, or industrial water, for such purposes to preserve the available water resources. A laboratory experiment was therefore conducted to study the effects of different physical and chemical treatments on sulphurous water intended for irrigation. The chemical treatments used were bentonite, nitric acid, activated carbon, and manganese oxide, while the physical treatment process examined was ventilation of various durations. The results showed that all treatments led to a reduction in the concentrations of iron, hydrogen sulphide, and sodium in the treated water, and that all methods of treatment and concentrations led to the reduction of SAR in the treated water. Some treatments led to an increase in the electrical conductivity, namely bentonite and nitric acid, while the other treatments led to lower electrical conductivity. All treatments and concentrations led to an increase in the concentration of magnesium in the water compared to that in the untreated water, which is considered a positive indicator.

1. Introduction

Water is one of the main resources that control the distribution of the population and human economic activities, especially with regard to drinking water and irrigation. Iraq relies mainly on surface water, rainwater, and groundwater to provide its water needs [1], yet the volume of water received from surface water has decreased by half in recent years due to a large number of projects, international political moves, and natural conditions. Most water in Iraq thus comes from rain [2], and due to the nature of the country’s desert and semi-desert climate, its rains are characterised by scarcity and fluctuation. In terms of the waters of rivers and their basins [3], most of the groundwater is sulphurous and requires treatment before use, and many physical, chemical, and biological methods have been used to remove hydrogen sulphide from water over the years [4, 5]. Assessing sulphurous water treatment for irrigation requires measuring various important variables to determine whether they are within acceptable limits. The most important value is the sodium adsorption ratio (SAR), an irrigation water quality parameter used in the management of sodium-affected soils [6]. This acts as an indicator of the suitability of water for use in irrigation based on the concentrations of the main alkaline and earth alkaline cations present in the water. The formula for calculating the sodium adsorption ratio (SAR) is [7].

\[
SAR = \frac{Na^{+2}}{\sqrt{(Ca^{+2}+Mg^{+2})}}
\]
The concentration of dissolved ions in treated sulphurous water (sodium concentration, calcium concentration, and magnesium concentration) was measured in this work in order to calculate the SAR value: the higher the SAR, the more dangerous the water, with acceptable limits being $0 < \text{SAR} < 10$ [8]. Electrical conductivity, hydrogen sulphide levels, bicarbonate concentration and iron content were also measured as important factors. The aim of the research was thus to examine several methods for treating sulphurous water chemically and physically and to test whether the resulting treated water is suitable for irrigation.

2. Materials and Methods
Sulphurous water was brought from an area of 90 km west of the city of Ramadi; this artesian well water flows with a discharge of 3 cubic metres per minute, and 100 litres were brought to the laboratory. Samples were also taken from the Euphrates and from puncture water from a trocar near the site of the experiments, for the purposes of examining the chemical properties of sulphurous water in comparison to other sources, as shown in Table 1.

| Table 1. Chemical properties of sulphurous water, Euphrates water, and puncture water from a trocar near the site of the experiment |
|---------------------------------------------------------------|
| The sample         | EC dS/m | pH  | Na+  | Ca+2 | Mg+2 | HCO3  |
| Sulphurous water   | 3.8     | 7.0 | 9.0  | 8.5  | 5.3  | 11.7  |
| Euphrates          | 1.4     | 7.6 | 7.5  | 2.4  | 1.8  | 1.1   |
| Puncture water     | 6.5     | 7.1 | 15.3 | 13.4 | 10.1 | 18.4  |

Chemical processes used in the experiments included the addition of bentonite clay, activated carbon, manganese oxide (MnO), and nitric acid (HNO3); one physical process (ventilation) was used in the experiment at various durations.

Chemical Processes:
1. Bentonite clay
Bentonite clay minerals were bought from a tile and ceramic factory in the Ramadi region of the Anbar Governorate, and bentonite clay was then added to the sulphurous water (1,780 mg/litre of sulphur) in 1, 1.5, 2, 2.5, and 3 g increments to 1-litre containers of sulphurous water. The containers were shaken for an hour at a speed of 6 cm per second using a shaker device, then filtered using filter paper, with the water retained for chemical analysis.

2. Activated carbon
Activated carbon was used in the treatment of sulphurous water in quantities of 0.5, 1, 1.5, 2, and 2.5 g to 1-litre containers of sulphurous water (1,780 mg/litre of sulphur). After shaking for one hour at a speed of 6 cm per second, the samples were filtered using filter paper, with the water was saved for the chemical analysis.

3. Manganese oxide (MnO).
Manganese oxide was used to treat sulphurous water (1,780 mg/litre of sulphur) at concentrations of 0.1, 0.2, 0.3, 0.4, and 0.5 g in a 1-litre container. The solutions were shaken for one hour at 6 cm per second using a vibrating device, and then filtered through filter paper, with the water saved for chemical analysis.

4. Nitric acid (HNO3)
Nitric acid was used in the treatment of sulphurous water (1,780 mg/litre of sulphur) by adding 1, 2, 3, 4, and 5 ml of nitric acid to 1-litre containers of sulphur water. After that, the solutions were shaken for one hour using the shaker device, and then the water was filtered using filter paper and saved for chemical analysis.

5. Physical process

5.1. Durations of Ventilation

Ventilation was used in the treatment of sulphur water (1,780 mg/litre of sulphur) by applying an air injection device to water samples for 1, 2, 3, 4, and 5 hours. The treated water was preserved for chemical analysis.

3. Discussion and Results

Several important and specific properties and limits of irrigation water specifications were examined:

3.1. Electrical conductivity

Figure 1 shows the effect of treatment with different concentrations of various treatment materials (activated carbon, bentonite, manganese oxide, nitric acid, and ventilation) on electrical conductivity. The results show that the electrical conductivity of untreated sulphurous water is 3.8 dS.m-1. Some treatments using bentonite led to an increase in electrical conductivity: adding concentrations of 2, 2.5, or 3 g of bentonite to a litre of sulphur water led to conductivity of 3.82 dS.m-1 on average, a 1% improvement compared to untreated sulphurous water. The addition of concentrations of 1.0 or 1.5 g of bentonite to a litre of sulphurous water led to conductivities of 3.72 and 3.77 dS.m-1, respectively, however, decreases of 2 and 1% as compared to untreated sulphurous water.

Ventilation treatment also led to a decrease in the electrical conductivity, with ventilation durations of 1, 2, 3, 4, or 5 hours leading to decreases in electrical conductivity of 3%, 4%, 9%, 10%, and 10% as compared to untreated sulphurous water (3.69, 3.46, 3.44 and 3.44 dS.m-1, respectively).

Treatment with activated carbon also led to a decrease in electrical conductivity, with the addition of 0.5, 1.0, 1.5, 2.0, or 2.5 grams of activated carbon per litre of sulphur water reducing the electrical conductivity to 3.69, 3.46, 3.44, and 3.44 dS.m-1, respectively, for 3%, 4%, 9%, 10%, and 10% reductions in conductivity compared to untreated sulphurous water.

Treatment using manganese oxide further led to a decrease in the electrical conductivity: adding 0.1, 0.2, 0.3, 0.4, or 0.5 g concentrations reduced electrical conductivity to 3.55 dS.m-1 on average, a decrease of 7% compared to untreated sulphurous water.

Treatment using nitric acid also led to a decrease in electrical conductivity, with adding 1, 2, or 3 ml of nitric acid to litres of sulphur water reducing the electrical conductivity to 3.39, 3.52, and 3.67 dS.m-1, respectively, giving reduction rates of 11%, 7%, and 3%, respectively, as compared to the untreated sulphurous water. The addition of 4 or 5 ml of nitric acid to sulphur water increased the electrical conductivity to 3.85 and 3.92 dS.m-1, respectively, however, showing increases of 1 and 3% as compared to untreated sulphur water.

The treatments that led to the greatest increase in electrical conductivity were the addition of bentonite at concentrations of 2.0, 2.5, or 3.0 g/litre, and treatment with nitric acid at concentrations of 4 or 5 ml/litre of sulphurous water. This can be attributed to the fact that these treatment processes encourage the formation of complex salts through chemical reactions in the treated water. All other treatments led to a reduction in electrical conductivity, perhaps due to adsorption processes that occurs with the addition of processors such as ions involved in the synthesis of some salts [9], or to the deposition processes of ions involved in the synthesis of such salts [10].
3.2. Hydrogen sulphide

Figure 2. shows the effect of treatment with different concentrations of treatment materials (activated carbon, bentonite, manganese oxide, nitric acid, and ventilation) on hydrogen sulphide concentrations in sulphurous water. The results show that the hydrogen sulphide concentration of untreated sulphur water is 234.6 mg per litre.

Treatment with nitric acid led to a decrease in the concentration of hydrogen sulphide, with the highest concentration of nitric acid (5 ml per litre of sulphurous water) reducing the concentration of hydrogen sulphide to 24 mg per litre, an 88% reduction compared to untreated sulphurous water.

Treatment with manganese oxide also led to a decrease in the concentration of hydrogen sulphide; adding the highest concentration of 0.5 mg. per litre reduced the concentration of hydrogen sulphide to 62.4 mg per litre, a 75% decrease.

Bentonite treatment also produced a decrease in the concentration of hydrogen sulphide, as adding the highest concentration of 3.0 g of bentonite to a litre of sulphur water reduced the concentration of hydrogen sulphide to 62 mg per litre, a decrease of 74% as compared to untreated sulphurous water.

Activated carbon similarly contributed to a decrease in the concentrations of hydrogen sulphide, with the highest concentration of 2.5 g activated carbon per litre of sulphurous water reducing the concentration of hydrogen sulphide to 96 mg per litre, a decrease of 59%.

Ventilation also decreased the concentration of hydrogen sulphide: the highest ventilation time (5 hours) reduced the concentration of hydrogen sulphide to 144 mg per litre, a decrease of 40% compared to untreated sulphurous water.

All treatment methods led to a decrease in the concentration of hydrogen sulphide in the treated water as compared to the untreated sulphur water [11, 12]. The most significant reductions in the concentration of hydrogen sulphide occurred from treatment with nitric acid, followed by manganese oxide, bentonite, activated carbon, and ventilation.
3.3. Concentration of dissolved ions

3.3.1. Sodium concentration.

Figure 3 shows the effect of treatment with different concentrations of different treatment materials (activated carbon, bentonite, manganese oxide, nitric acid, and ventilation) on sodium concentrations. The results show that the sodium concentration in untreated sulphurous water is 9.0 mmol per litre.

Treatment with activated carbon decreased the sodium concentration: adding concentrations of 0.5, 1.0, 1.5, 2.0, or 2.5 g of activated carbon per litre of sulphur water reduced the sodium concentrations to 5.2, 5.4, 5.5, 5.6, or 5.7 mmol per litre, respectively. The highest percentage of decrease was seen with a concentration of 0.5 g of activated carbon per litre of sulphur water, a 42% decrease as compared to untreated sulphurous water.

Adding 0.1 g manganese oxide to a litre of sulphurous water reduced the sodium concentration to 5.2 mmol per litre, a 42% reduction, while the other concentrations of MnO (0.2, 0.3, 0.4, or 0.5 g) reduced the sodium concentration to 6.6 mmol per litre, a 27% decrease compared to untreated sulphurous water.

Ventilation treatment also decreased the sodium concentrations. Ventilation for 1, 2, 3, 4, or 5 hours reduced the sodium concentration to 6.5 mmol per litre, a 28% reduction, on average as compared to untreated sulphurous water.

Treatment with bentonite also led to decreases in sodium concentrations. The addition of bentonite reduced the sodium concentration to 6.9 mmol per litre, a 42% reduction, on average as compared to untreated sulphurous water.

Treatment using nitric acid similarly reduced the sodium concentration to 7 mmol per litre on average, a 21% reduction compared to untreated sulphurous water.

All treatment methods and concentrations resulted in a decrease in the sodium concentration in treated water as compared to the concentration of sodium in untreated sulphurous water. This corresponds with the findings of [10, 13]. The order of the best sodium concentration reductions was Activated carbon> Manganese oxide> Ventilation> Bentonite> Nitric acid.
3.3.2 Calcium concentration

Figure 4 shows the effects of treatment with different concentrations of different treatment materials (activated carbon, bentonite, manganese oxide, nitric acid, and ventilation) on calcium concentrations. The results show that the calcium concentration in untreated sulphur water is 8.5 mmol per litre.

Treatment using manganese oxide resulted in a decrease in calcium concentration. The addition of 0.1 g manganese oxide to a litre of sulphurous water reduced the calcium concentration to 8.3 mmol per litre, a 2% reduction compared to untreated sulphurous water, while other concentrations reduced the calcium concentration to 5.6 mmol per litre, a 34% decrease.

Most treatment with nitric acid also reduced the concentration of calcium to 7.6 mmol per litre on average, an 11% reduction compared to untreated sulphurous water. However, for treatment with only 1 ml of nitric acid added to a litre of water, no effect on calcium concentration could be observed.

Ventilation treatment also reduced calcium concentration to 7.8 mmol litre, an 8% average reduction compared to untreated sulphurous water.

Treatment with activated carbon decreased the calcium concentration in some cases: concentrations of 0.5 or 1.0 g activated carbon per litre of sulphurous water reduced the calcium concentration to 8.3 mmol per litre, while other concentrations investigated did not affect the calcium concentration in any way.

Adding bentonite led to an increase in the concentration of calcium in some cases. Adding 2.0, 2.5, or 3.0 g of bentonite to a litre of sulphur water resulted in an increase in the concentration of calcium to 8.6 mmol per litre, an increase of 1% compared to untreated sulphurous water. However, adding 1.0 or 1.5 g of bentonite to a litre of sulphurous water had no effect on calcium concentration.

The generally low calcium concentration and the effects of most treatment methods are confirmed by other researchers, including [12]. Arranging treatments in terms of the most effective at reducing calcium concentration gives the sequence: manganese oxide > nitric acid > ventilation > activated carbon.
3.3.3. Magnesium concentration

Figure 5. shows the effects of treatment with different concentrations of different treatment materials (activated carbon, bentonite, manganese oxide, nitric acid, and ventilation) on magnesium concentration. The results show that the magnesium concentration in untreated sulphurous water is 5.3 mmol per litre. Treatment using manganese oxide resulted in increases in magnesium concentrations. The addition of 0.1, 0.2, 0.3, 0.4, or 0.5 g/litre MnO gave magnesium concentrations of 6.6, 8.4, 8.6, 8.7, and 8.7 mmol per litre, increases of 24%, 59%, 62%, 64%, and 64%, respectively, as compared to untreated sulphurous water.

Treatment with nitric acid also led to increases in the concentration of magnesium. Adding 1, 2, 3, 4, or 5 ml of nitric acid to a litre of sulphurous water led to concentrations of magnesium of 5.4, 6.4, 6.7, 7.1, and 7.6 mmol per litre, increases of 2%, 20%, 26%, 34% and 43%, respectively, compared to untreated sulphur water.

Treatment with bentonite further led to an increase in the concentration of magnesium of 6.8 mmol per litre on average, a 28% increase as compared to untreated sulphurous water. Adding activated carbon also led to an increase in the concentration of magnesium: all tested concentrations of activated carbon increased the magnesium concentration to 6.8 mmol per litre, an increase of 28% as compared to untreated sulphurous water.

Ventilation treatment also led to an increase in the concentration of magnesium, with 6.3 mmol per litre seen for 1- and 2-hour ventilation periods, an increase of 19% on average, and 5.8 mmol per litre for other durations, a 10% increase as compared to untreated water.

All treatment methods and concentrations led to an increase in the concentration of magnesium in treated water as compared to the concentration in untreated sulphurous water, in agreement with both [14, 15]. The most significant increase in the concentration of magnesium was found with the addition of manganese oxide, followed by nitric acid, bentonite, activated carbon, then ventilation.
3.3.4. Sodium Adsorption Ratio (SAR)

Figure 6 shows the effect of treatment with different concentrations of different treatment materials (activated carbon, bentonite, manganese oxide, nitric acid, and ventilation) on the sodium adsorption ratio. The results show that the sodium adsorption ratio (SAR) in untreated sulphurous water is 2.43 mmol per litre.

Treatment with nitric acid resulted in a decrease in the SAR value, reducing the SAR to 1.85 on average, a 24% reduction as compared to untreated sulphurous water. Bentonite additions also led to a decrease in the value of SAR, to 1.76 on average, a 28% reduction compared to untreated sulphurous water.

Treatment with ventilation also led to decreases in the SAR value, with ventilation for periods of 1, 2, 3, 4, or 5 hours decreasing SAR to 1.66, 1.74, 1.78, 1.78, and 1.78, respectively, decreases of 32%, 28%, 27%, 27%, and 27% as compared to untreated sulphurous water.

Manganese oxide also led to a decrease in the SAR value, with 0.1 g per litre reducing the SAR to 1.35, a 44% decrease as compared to untreated sulphurous water, and the additions of 0.2, 0.3, 0.4, or 0.5 g per litre reducing the SAR to 1.75 on average, a decrease of 28%. Adding carbon also led to a decrease in SAR value, to 1.42 on average, a decrease of 41% as compared to the untreated sulphurous water.

All treatment methods and concentrations resulted in a decrease in the value of SAR in treated water as compared to the value of SAR in untreated sulphurous water. The most effective methods for reducing the value of the SAR are, in order, activated carbon> manganese oxide> bentonite> ventilation> nitric acid. Additionally, in all cases, the value of SAR <10, meaning that the treated water is suitable for irrigation for most land types [16].
3.4. Bicarbonate concentration

Figure 7 shows the effects of treatment with different concentrations of different treatment materials (activated carbon, bentonite, manganese oxide, nitric acid and ventilation on bicarbonate concentration. The laboratory results showed that the concentration of bicarbonate in untreated sulphurous water is 11.7 mmol per litre.

Treatment with nitric acid led to a decrease in bicarbonate concentration. Adding 1, 2, 3, 4, or 5 ml of nitric acid to a litre of sulphurous water reduced the concentrations of bicarbonate to 9.5, 9.7, 10.3, 11.1 and 11.4 mmol per litre, respectively, decreases of 24%, 22%, 12%, 5%, and 3% as compared to untreated sulphur water; thus, increasing the concentration of nitric acid has less effect on reducing the concentration of bicarbonate.

Treatment with activated carbon also led to a decrease in the concentration of bicarbonate. Adding 0.5, 1.0, 1.5, 2.0, or 2.5 g activated carbon per litre of sulphur water reduced the concentrations of bicarbonate to 11.0, 9.5, 9.1, 9.1, and 9.0 mmol per litre, respectively, reductions of 6%, 19%, 22%, 22%, and 23% as compared to untreated sulphurous water; thus, increasing the activated carbon concentration leads to a decrease in the concentration of bicarbonate.

Ventilation also led to a reduction in the concentration of bicarbonate, to 8.5 mmol per litre on average, a reduction rate of 27% as compared to untreated sulphurous water. Treatment using manganese oxide also led to a decrease in the concentration of bicarbonate, to 8.7 mmol on average, a reduction rate of 26%.

A further decrease in bicarbonate concentrations was seen with bentonite: adding 1 g of bentonite to a litre of sulphurous water reduced the bicarbonate concentration to 9.0 mmol per litre, a reduction rate of 23% as compared to untreated sulphurous water. The addition of 1.5, 2.0, 2.5, or 3.0 g of bentonite per litre of sulphurous water reduced the concentration of bicarbonate to 8 mmol per litre on average, a reduction of 32% as compared to untreated sulphurous water.

All treatment methods and concentrations led to a decrease in the concentration of bicarbonate in the treated water as compared to the concentration of bicarbonate in untreated sulphurous water [17]. The most influential treatment was bentonite, followed by ventilation, manganese oxide, activated carbon, and nitric acid.
3.5. Iron
The results show that the concentration of iron in untreated sulphur water is 0.44 mg per litre. The concentrations of iron in sulphurous water treated with bentonite were 0.42, 0.22, 0.22, 0.12, and 0.05 mg per litre, respectively, when using concentrations of 1.0, 1.5, 2.0, 2.5, and 3.0 g of bentonite per litre of sulphur water. The observed effect of bentonite on iron concentration was thus consistent with [18]. The concentrations of iron in sulphur water treated with nitric acid were 0.5, 0.61, 0.66, 0.68, and 0.68 mg per litre for 1, 2, 3, 4 and 5 ml of nitric acid per litre of sulphurous water, respectively. The concentrations of iron in sulphurous water treated with manganese oxide were 0.23, 0.23, 0.30, 0.31, and 0.31 mg per litre for 0.1, 0.2, 0.3, 0.4, and 0.5 g per litre, respectively. The iron concentration in sulphurous water treated with activated carbon was 0.16 mg per litre on average for all concentrations used in the treatment. The iron concentration in sulphurous water treated with ventilation was 0.03 mg per litre on average for all periods used in the treatment. The sulphurous water both before and after most treatment contains lower concentrations of iron than the critical concentrations for irrigation use, however; the limit per litre for iron in water for irrigation purposes is 0.5 mg, according to [19, 20, 21]. Figure 8 shows the effects of different treatments on iron concentration, with only the water treated with nitric acid exceeding the recommended amount.

Figure 7. The effects of different treatments on sodium concentration
4. Conclusion
In conclusion, different treatment materials, which are activated carbon, bentonite, nitric acid and manganese oxide in their different concentrations, have an effect in treating sulfur water and removing hydrogen sulfide. The treatment of sulfurous water with nitric acid removed the highest percentage of hydrogen sulfide and caused a decrease of 88% compared to before the treatment. The best treatment for removing hydrogen sulfide was with the use of nitric acid, followed by treatment with manganese oxide and then bentonite.

Acknowledgements
We are grateful to all staff in the College of Agriculture, University of Anbar for tremendous help.

5. References
[1] Al-Furaiji M H O, Karim U F, Augustijn D C, Waisi B I H and Hulscher S J 2016 Evaluation of water demand and supply in the south of Iraq. Journal of Water Reuse and Desalination, 6(1): 214-226.
[2] Sulaiman S O, Kamel A H, Sayl K N and Alfadhel M Y 2019 Water resources management and sustainability over the Western desert of Iraq. Environmental Earth Sciences, 78(16): 495.
[3] Akanda A, Freeman S and Placht M 2007 The Tigris-Euphrates River basin: mediating a path towards regional water stability. Al Nakhlah, 31.
[4] Krayzelova L, Bartacek J, Diaz I, Jeison D, Volcke E I and Jenicek P 2015 Microaeration for hydrogen sulphide removal during anaerobic treatment: a review. Reviews in Environmental Science and Bio/Technology, 14(4): 703-725.
[5] Misra A K 2014. Climate change and challenges of water and food security. International Journal of Sustainable Built Environment, 3(1): 153-165.
[6] Asadollahfardi G, Hemati A, Moradinejad S and Asadollahfardi R 2013. Sodium adsorption ratio (SAR) prediction of the Chalghazi river using artificial neural network (ANN) Iran. Current World Environment, 8(2): 169-178.
[7] Hooshm A, Delgh M, Izadi A and Aali K A 2011. Application of kriging and cokriging in spatial estimation of groundwater quality parameters. African Journal of Agricultural Research, 6(14): 3402-3408.
[8] Fipps G 2003 Irrigation water quality standards and salinity management strategies. Texas FARMER Collection. pp3-18.
[9] Ranga S 2018. Bentonite used as natural coagulant and adsorbent: A. The Pharma Innovation Journal, 7(7): 155-157.

[10] Nguyen T A and Juang R S 2013 Treatment of waters and wastewaters containing sulphur dyes: a review. Chemical Engineering Journal, 219 (2013): 109–117.

[11] Asaoka S, Yamamoto T, Kondo S and Hayakawa S 2009. Removal of hydrogen sulphide using crushed oyster shell from pore water to remediate organically enriched coastal marine sediments. Bioresource Technology, 100(18): 4127-4132.

[12] Edwards S, Alharthi R and Ghaly A E 2011. Removal of hydrogen sulphide from water. American Journal of Environmental Sciences, 7 (4): 295-305.

[13] Duranceau S J, Trupiano V M, Lowenstein M, Whidden S and Hopp J 2010. Innovative hydrogen sulphide treatment methods: moving beyond packed tower aeration. Florida Water Resources Journal, 62: 4-14.

[14] Maree J P, Greben H A and De Beer M 2004. Treatment of acid and sulphate-rich effluents in an integrated biological/chemical process. Water S.A., 30(2): 183-189

[15] Phocaides A 2001. Hand book on pressurized irrigation Techniques FAO consultant.

[16] Bauder T A, Waskom R M, Sutherland P L and Davis J G 2011. Irrigation water quality criteria. Fact sheet (Colorado State University. Extension). Crop series; no. 0.506.

[17] Siener R, Jahn A and Hesse A 2004. Influence of a mineral water rich in calcium, magnesium and bicarbonate on urine composition and the risk of calcium oxalate crystallization. European Journal of Clinical Nutrition, 58(2): 270-276.

[18] Tahir S S and Rauf N 2004. Removal of Fe (II) from the wastewater of a galvanized pipe manufacturing industry by adsorption onto bentonite clay. Journal of Environmental Management, 73(4): 285-292.

[19] ACSAD, Center for Scientific and Environmental Research, University of Damascus, 1997. Report on meteorological and toxicological monitoring of pollution resulting from the use of Barada River and groundwater for irrigation of crops.

[20] Kisku G C, Barman S C and Bhargava S K 2000. Contamination of soil and plants with potentially toxic elements irrigated with mixed industrial effluent and its impact on the environment. Water, Air and Soil Pollution, 120(1-2): 121-137.

[21] Kretschmer N, Ribbe L and Gaese H 2002. Wastewater reuse for agriculture. Technology Resource Management and Development-Scientific Contributions for Sustainable Development, 2: 37-64.