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Evaluation of wastewater post-treatment options for reuse purposes in the agricultural sector under rural development conditions

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ABSTRACT

Reuse of wastewater is a sustainable and renewable source of water, mainly used in the agricultural sector and can contribute to rural development. Agriculture is the second highest sector for water consumption in the Gaza Strip, using more than 50% of water abstractions from the stressed polluted Gaza's coastal aquifer. This paper aims to present and evaluate two available wastewater post-treatment options which could be employed to reuse wastewater for agriculture in Gaza: sand filtration using a textured geo-membrane sand filter and the Soil Aquifer Treatment (SAT) system. This evaluation is based on applying hierarchy grey relational analysis and the comparison matrix through an environmental assessment for each option using a semi-empirical methodology that combines results from field tests and computer hydrological simulations. In addition, it is based on a social and economic and the operational aspects for the Gaza City Wastewater Treatment Plant (WWTP) and its infiltration basin. The evaluation factors for the two options are juxtaposed in a Comparison Matrix with associated weighted scores and pre-defined scales to quantify the evaluation process before using the hierarchy grey relational analysis. The results show that the operational costs and the environmental aspects are the main factors that affect the evaluation process for wastewater post-treatment options. The sand filtration (with textured geo-membrane) option is ranked higher than the SAT system for this particular case study with an overall integrated grey relational grade equal to 0.3276, compared to 0.2596 for the SAT system.

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1. Introduction

Wastewater reuse is one of the main options to develop non-conventional water resources because it can be considered as a renewable and sustainable source of water [24]. This water resource can be used for agricultural purposes or for groundwater recharge. The reuse of reclaimed wastewater reduces the gap between the water demand and the supply. It can also improve the environment by reducing the load of environmental contaminations [22], as well as providing economic and health advantages such as reducing the cost of wastewater disposal as well as the cost for irrigation water [18,29]. In addition to that, long term

investment in the management system for agricultural water is a challenge, especially in the concern of rural development [11].

Water scarcity is one of the key difficulties and challenges facing human society across the world. The Gaza Strip suffers from water scarcity due to the continuously over-pumping and the huge gap between water demand and water supply, which has caused both water quantity and quality problems [5,32]. The situation is further deteriorated and exacerbated by climate change impacts [14,13] and the continuous substantial increases in population leading increased water demand. As such, the need of finding new unconventional water resources for the agricultural sector becomes of paramount importance for the Gaza Strip. Using treated wastewater for irrigation purposes is one of the most environmental friendly available options [16] and according to the Palestinian Water Authority (PWA) strategic plan, this option will be feasible for the future.

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Fig. 1. Methodology flow chart.

In the Gaza Strip there are 5 Wastewater Treatment Plants (WWTPs), but the treated effluent quality does not meet the minimum regulations for irrigation purposes or even for discharge to water bodies. The main reason for this bad efficiency is the overloaded situation for these WWTPs, hydraulically and biologically [15]. In order to overcome this obstacle, a post treatment process is needed to provide a higher level of treated wastewater that meets the reuse regulations [33,12], with minimum direct and indirect costs and impacts [6].

This paper provides a semi-empirical methodology that combines results from field tests and computer hydrological simulations, to evaluate two suitable wastewater post-treatment options: sand filtration using a textured geo-membrane and Soil Aquifer Treatment (SAT) based on social, economic and environmental aspects.

Sand filtration using a textured geo-membrane is an open slow sand filter with multiple layers consisting of coarse gravel, sand, fine sand and textured geo-membrane. The filter is fed by wastewater effluent [17].

SAT can provide post treatment to WWTP effluents by land-based managed aquifer recharge technology. SAT provides physical, chemical and biological treatment processes in order to improve

the quality of wastewater effluent by its infiltration through soil layers to yield water of acceptable quality for reuse purposes [1,2,36]. In this paper the environmental sub-assessment process for SAT has been carried out through groundwater simulations for flow and tracer pollutant transport.

The methodology in this paper is based on identifying the optimized solution by applying a hierarchy grey relational analysis [35] followed by a comparison matrix [19,9] which compares environmental and socioeconomic aspects [27] for each option using practical field full scale experimental results and hydrological simulations. In addition it is based on a social and economic survey as well as the operational aspects for the Gaza City WWTP and its infiltration basin, as a case study in a region with stressed water situation.

2. Materials and methods

The comparison and assessment of alternative mitigation strategies for an environmental phenomenon is a critical task and can be very sensitive to the factors which participate in the process. As such, careful planning is required before any analysis is started: Fig. 1 shows the general flowchart for the methodology that is used

Fig. 2. Study area location map.

in this study. The methodology starts with selecting the available options that need to be compared and evaluated, then collecting the related data. There are 4 main steps involved in the process: (i) simulating the SAT system and the full-scale geo-membrane sand filtration, (ii) selecting and building the factors/weights matrix, (iii) building the general comparison matrix and (iv) juxtaposing all these steps using the hierarchy grey relational analysis.

2.1. Study area

This study is focused on the central WWTP of the Gaza Strip, which is located to the south-east of Gaza City, as shown in Fig. 2. The plant receives about 60,000 m³/day of raw wastewater. The designed location for SAT infiltration basin, which is considered for this study, is planned to be in a northern side of the plant with an area about 13,000 m². This WWTP has been selected for this study because it has the average biological load among the five WWTPs in Gaza Strip and its infrastructure could most easily be adapted for any post-treatment recommendations coming out of the process.

The site is covered with a sand layer with a thickness between 3 and 12 m with clay lenses present in the unsaturated zone. The layers are semi permeable which means that they allow water to pass through. The average hydraulic conductivity of the unsaturated zone is 18 m/day, which is estimated through filed ring infiltrometer experiment [23]. The groundwater level is found at approximately 0.35 m above sea level, which means that the thickness of the saturated aquifer varies between approximately 30 m and 40 m.

2.2. Soil Aquifer Treatment (SAT) system impacts model

A model was used to study the impacts of infiltrated treated wastewater on groundwater and to determine the potential quantity of treated wastewater that can be recharged in the SAT system. The model is based on investigating the hydrogeological properties, lithological description and geological setting of the infiltration basin. The groundwater model was built to predict water levels, extent of the recharge mound, spreading radius, transport time, pollution path, and the pollution plume concentration from the proposed discharge rate of treated wastewater to the infiltration basin. The model also provides and tests a design of the recovery scheme for the SAT system.

MODFLOW, MODPATH and MT3d models are used in the simulation process [10,14]. The simulation for the SAT system is done through a fine grid model that is nested in a calibrated regional groundwater model grid. The regional model grid consists of a finite difference mesh of 184 columns and 60 rows. The grid is regular with a cell size of 250 m × 250 m, while the grid size for the nested model in 25 m × 25 m, which is applied to infiltration basin area. The boundary conditions in the model are assigned as general flow boundaries in the north and the south where the groundwater flow is perpendicular to the coast line. A zero constant head boundary is assigned for the western boundary with the Mediterranean Sea, and a general head boundary is assigned for the east boundary according to the baseline water levels data. For the purpose of model construction, the aquifer system is schematized in 7 layers. There are 4 sub aquifers of sand with gravel (Kurkar formation) and 3 major clay layers. The base of the model consists of the Sakiye

Table 1

Weights and ranking for criteria and indices considered for selection of the wastewater post-treatment option.

Criteria	Rank	Weight	Indices	Sub-rank	Sub-weight
C1 economic criterion	1	0.5371	I1 capital cost (\$)	1	0.6371
			I2 O&M unit cost (\$) for each cubic meter	3	0.1052
			I3 land area squared meter	2	0.2581
C2 environmental and social criterion	2	0.3581	I4 removal efficiency	3	0.2271
			I5 effects on saturated zone (groundwater)*	4	0.1904
			I6 effects on unsaturated zone*	2	0.2483
			I7 Social acceptance*	1	0.3345
C3 administrative criterion	3	0.1052	I8 professional skills required for operation and maintenance*	1	1

* The star sign in the table represents the quantitative data of qualitative indices, which are determined by the four-grade classification criteria (0.9—excellent, 0.7—good, 0.5—moderate, 0.3—poor).

Table 2

Q8 The average monitored values for geo-membrane system efficiency parameters.

Sample	Parameters						
	COD (mg/l)	BOD5 (mg/l)	TSS (mg/l)	NH4-N (mg/l)	TKN (mg/l)	NO3 (mg/l)	FC (CFU/100ml)
Feed	188	66	83	38	42	1	1×10 ⁶
Geo-membrane with reeds	130	30	17	30	33	15	5×10 ³
Geo-membrane without reeds	157	27	12	18	18	15	5×10 ³

Table 3

Alternatives data summary and objective hierarchy for the wastewater post-treatment alternative selection.

Goal	Criteria	Indices	Options	
			Textured geo-membrane	SAT
To achieve maximum integrated value (the best option)	C1 economic criterion	I1 capital cost (\$)	1,830,000	1,300,000
		I2 O&M unit cost (\$) for each cubic meter	0.012	0.147
		I3 land area squared meter	10,000	13,000
	C2 environmental and social criterion	I4 removal efficiency	0.63	0.82
		I5 effects on saturated zone (groundwater)*	0.9	0.3
		I6 effects on unsaturated zone*	0.9	0.3
		I7 social acceptance*	0.5	0.7
	C3 administrative criterion	I8 professional skills required for operation and maintenance*	0.7	0.3

Table 4

Normalized data of each option and the resultant primary and secondary grey relational coefficients for index level with the final integrated grey relational grade for each optional scheme.

Criteria	Indices	Normalized values of original data		Normalized weighted primary grey relational coefficients		Normalized weighted secondary grey relational coefficients	
		Textured geo-membrane	SAT	Textured geo-membrane	SAT	Textured geo-membrane	SAT
C1 economic criterion	I1 capital cost (\$)	0.7104	1	0.4526	0.6371	0.1461	0.1511
	I2 O&M unit cost (\$) for each cubic meter	1	0.0816	0.1052	0.0086		
	I3 land area squared meter	1	0.7692	0.2581	0.1985		
C2 environmental and social criterion	I4 removal efficiency	0.7683	1	0.1745	0.2271	0.0763	0.0634
	I5 effects on saturated zone (groundwater)	1	0.3333	0.1904	0.0635		
	I6 effects on unsaturated zone	1	0.3333	0.2483	0.0828		
	I7 social acceptance	0.7143	1	0.2389	0.3345		
C3 administrative criterion	I8 professional skills required for operation and maintenance	1	0.4286	1	0.4286	0.1052	0.0451
Integrated grey relational grade						0.3276	0.2596
Rank						1	2

Fig. 3. (A) The filters dimensions and layout, (B1) the layers above the geo-membrane textile layer in the slow sand filter, (B2) the layers above the geo-membrane textile layer in the reed bed filter, (C) general pictures for the site and the storage tank.

group, assumed to be impermeable. The geological data are taken from the Palestinian Water Authority data bank. Hydraulic property values are assigned based on the hydrogeological investigation through filed pumping test experiment and previous literature [13,14,25,21,30,20]. The hydraulic conductivity is assumed to be constant for each layer. The horizontal hydraulic conductivity of the sandstone aquifer is 32 m/d, specific storage is 1×10^{-6} (m^{-1}) specific yield is 0.24 and total porosity is 0.30. The horizontal hydraulic conductivity of the clay layer is 0.3 m/d, specific storage is 1×10^{-6}

(m^{-1}), specific yield is 0.10 and total porosity is 0.45. The vertical conductivity was set to 10% of the horizontal hydraulic conductivity. The spatial average recharge is estimated as 108 mm/year. For the SAT infiltration basin an infiltration rate value 0.77 m/day is assigned. The model is a transient model and has a yearly time step for 9125 days. The flow and pollutant transport models are calibrated and validated. The model calibration and validation shows (8.769% < 10%) for normalized root mean square (RMS) and 81% percent of agreement with the observed value for flow and chloride

Fig. 4. The hierarchy decision model for optimizing wastewater post-treatment alternative selection. At the top of the hierarchy, the overall objective is to get the maximum alternative option grade. The criteria considered in the selection of optimal alternative lie at the criterion level, which mainly consist of economic aspect, environmental and social aspect and administrative criterion. The designed hierarchy takes the indices in Table 1 into account, such as capital cost, O&M cost, land area, energy consumption, removal efficiencies etc. The scheme level lists the two alternative to be compared and evaluated.

Fig. 5. Recovery wells system.

concentration. The simulation option is applied for the SAT system because of the economical, practical and the environmental obstacles and difficulties to implement a full-scale project.

A social acceptance survey was carried out using a statistical sample out of the community surrounded by WWTP. The sample size is 50 farmers out of 500 farmers in the surrounding community in the target area, the designed survey is a set of questions that measure the general social acceptance for the post-treatment option and it measures the ability of farmers to pay for the service. The results from the survey were analyzed using severity index procedure [3] and the overall result for the option is determined by the four-grade classification criteria (0.9—excellent, 0.7—good, 0.5—moderate, 0.3—poor). The capital and operational cost for SAT system option is calculated for this option and a specific cost figure is provided in order to use it in the comparison process.

2.3. Textured geo-membrane sand filter full scale project

The geo-membrane sand filtration system that is used in this full-scale project evaluation contains 3 slow sand filters and 2 reed bed sand filters as shown in Fig. 3. This system is a stratified sand filter improved by a layer of geo-membrane texture at the bottom of each sand filter, which is the main reason of naming the system by geo-membrane sand filtration system. These filters work in a parallel-flow design situation. One central header of inlet channel feeds the filters with the input water. Each filter has a drained UPVC pipes with diameter of 200 mm and slope 1–2% the last layer in each filter is the geo-membrane textile layer followed by clay layer in order to prevent water percolation in to the unsaturated zone layers to the aquifer. The designed capacity for this system is 1000 m³/day with rate of 62.5 m³/h for 16 working hours. This system is provided

Fig. 6. The simulated groundwater mound (MSL) resulting from the continuous infiltration for the SAT system infiltration basin in the cases (A) without recovery system after 7300 days and (B) With recovery system after 7300 days.

by a storage tank with 600 m³ to be used to store the treated effluent for subsequent irrigation purposes.

The system is an open filtration system that allows water to flow through the filter layers with an overflow emergency channel. The filtered water is collected by a drainage layer in the bottom of each filter. The filter bed is 1.5 m high and consists of pebbles, coarse gravel, sand, fine sand and geo-membrane textile, respectively from top to bottom, as shown in Fig. 3.

In order to evaluate this system, a complete monthly chemical and biological (Faecal Coliform) water and soil analysis was implemented. The influent and effluent water were chemically and biologically analyzed. The capital and operational costs are calcu-

lated for this option and a specific cost figure is provided in order to use it in the comparison process.

Composite soil samples from the unsaturated zone in the irrigated area were collected from 6 locations three times over the year for one year, the sampling process was designed to address the changes regarding applying the treated wastewater on the soil, so it had to be before, after and during the irrigation season, as three important time steps the soil needs to be investigated. The samples were collected at different depths (0–30, 30–60, and 60–90 cm) in each site. The samples are characterized physically and chemically in order to use the results in this comparison study. In addition to that, groundwater samples are collected from 8 agricultural wells in

Fig. 7. The simulated particles path lines from the continuous infiltration for the SAT system infiltration basin in the cases (A) without recovery system after 7300 days and (B) With recovery system after 7300 days.

the study area. The chemical analysis, COD, BOD, TSS, DO, pH, major cations and anions, are implemented for the effluent, influent, soil and groundwater. A baseline groundwater quality is prepared in order to use it in the simulation process for SAT system and then use it in the comparison and evaluation process.

A survey for services satisfaction by questioners for a statistically representative sample from the surrounded community and the farmers to cover the social acceptance aspect was also performed for this study. The same previous sample of farmers, that was used to evaluate the social acceptance of SAT system, is used to evaluate the social aspects for this option, the designed survey is a set of questions that measure the general social acceptance for the post-treatment option and it measures the ability of farmers to pay

for the service. The results from the survey were analyzed using severity index procedure [3] and the overall result for the option is determined by the four-grade classification criteria (0.9—excellent, 0.7—good, 0.5—moderate, 0.3—poor).

2.4. Hierarchy grey relational analysis and comparison matrix

The comparison matrix and the hierarchy grey relational analysis approach are used to juxtapose and quantify the likert scale results [8] from the simulation process for SAT system and the full-scale geo-membrane sand filtration project. The process of comparison is done using a defined criteria and indices (see Table 1),

which are quantified by a panel of experts in this area depending on the available literature [19,35,34].

The hierarchy grey relational analysis approach is an innovative systematic methodology for optimal selection and evaluation. This approach is based on the application of analytic hierarchy process (AHP) and grey relational analysis (GRA). This method can be applied for the very complex multi-criteria decision-making process in order to get a decision based on scientific criteria [19,34,35].

Fig. 4 presents the hierarchy decision model used for this analysis. This model contains four levels, which start with the overall objective of the optimal wastewater post-treatment option. The second level contains three main criteria, economic (C1), environmental and social aspects (C2), and the administrative criteria (C3). The third level gives the indices, as sub-categories for each criteria, which are taken in the problem addressing. The last level contains the alternative options that the evaluation is carried out around. The hierarchical structure of the system allows for the relationships between factors to be compared between each pairwise. The three main criteria in the second level of the presented hierarchy in Fig. 4 are the main aspects that contain all the possible sub-aspects such as process complexity, running cost, and any other aspects may be considered. Table 1 shows ranks for the main criteria and sub-main criteria, these ranks are associated with the corresponding calculated weights, the higher weight gives the higher rank. The comparison and evaluation process are based on determining weights of alternatives with respect to the overall goal by taking into account elements in between. After decomposing the comparison and evaluation problem into a hierarchy, elements at given hierarchy level are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level. The pair wise comparisons were carried out using the verbal terms of the Saaty's scale, which used to assess the intensity of preference between two elements in order to facilitate the weighting process for quantifiable and non-quantifiable elements by applying Saaty recommended mathematical method [31,7,28], which is based on eigenvalues. Since the verbal judgments are constructed, these judgments can be converted into numbers by means of the scale. The previous procedure is repeated for aspects in each level from top level to the bottom in the hierarchy. The Judgmental process lead to comparisons matrix.

The comparison matrix (CA) can be as:

CA	C1	C2	C3
C1	1	C2,C1	C3,C1
C2	1/ C2,C1	1	C2,C3
C3	1/ C3,C1	1/ C2,C3	1

As part of the evaluation and comparison process, matrix manipulations are performed with created judgmental matrices to obtain final performance ratings of alternatives. The matrices of comparisons are converted into sets of weights (see Table 1). These weights illustrate the relative importance of the aspects at the same level in the hierarchy.

Some type of data (such as the capital cost) is much greater than others in terms of scale as shown in Table 3, so the data needs to be pre-processed to provide a normalized range for fair cross comparison (see Table 4).

Table 4 also shows the resulting primary and secondary grey relational coefficients. The calculations are conducted using the strong matrix computing toolbox of MatLab. The integrated grey relational grade vector can be obtained by multiplying the result-

ing secondary grey relational coefficient matrix by the weighting vector for the criterion level with respect to the overall objective.

3. Results and discussion

The SAT system simulation process shows that the most efficient recovery wells system should be located as shown in Fig. 5. This system contains 4 recovery wells, which are distributed to control the flow by manipulating the size of groundwater mound [4] and prevent pollution transport due to infiltration process. The recovery wells are designed to pump 120 m³/h for 20 h for each three day cycle as SAT system operational scenario (one day wet, two day dry). The total designed abstraction quantity from recovery wells system will be 120% of infiltrated water, which is 12,000 m³.

The simulation process for the system is implemented both with and without a recovery system in order to understand the impacts of the system on groundwater.

The simulated groundwater mound beneath the infiltration basin rises to approximately 6 m after 7300 days when no recovery system is simulated on the operation process, but the mound decreases from 6 to 1 m in the maximum point (as shown in Fig. 6) when the recovery wells are operated.

This simulation is transient flow and pollutant transport simulation, so the groundwater mound represents a transient flow results, however, [4] implements a steady state model to investigate the groundwater mound values. The geo-membrane appeared to have no effect on the groundwater mound.

In order to simulate the penetration of the infiltrated water to the groundwater layer through the unsaturated layers, MODPATH is used for tracking the particles and flow lines percolating from SAT's infiltration basin. The pathlines for the imaginary particles that are infiltrated in the recharge area spread radially about 500 m after 365 days, 1000 m after 1825 days, 1500 m after 3650 days, 1850 m after 5475 days and 2000 m after 7300 days for the results where no recovery wells are simulated. On the other hand, when the recovery wells are included in the system, the infiltrated water is controlled and not allowed to spread out. Hence, the recovery wells seem to be able to control the particles lines (see Fig. 7). The regional groundwater model simulation for the proposed irrigated water in the two options, SAT and geo-membrane filtration, shows an equivalent effects for the two options in the terms of irrigation water pollution tracking.

The solute transport model MT3D describes the process of advection, dispersion-diffusion and chemical reactions of the infiltrated water from the SAT system. The model set-up is conducted based on the results of the regional flow model. In order to study the solute transport due to dispersion, a conservative tracer is used, which does not degrade, absorb or even react with the unsaturated zone layers. The model assumes that the infiltration water has a concentration of 100 mg/l, while the tracer concentration in the aquifer is 0 mg/l. The 100 mg/l is considered as the reference concentration (100% injected water) and the simulated concentrations in the aquifer are expressed relative to this values. Thus, the tracer percentage enables how much of the original groundwater has been replaced by invading infiltration water to be known at a particular site. The results indicate that 90% of the infiltrated water from the SAT system is mixed with the aquifer water after 1 year beneath the recharge area as shown in Fig. 9.

The average chloride concentration for the infiltration water is 985 mg/l, which is extremely high because of seawater intrusion effects in Gaza coastal aquifer [14,25,26] that indirectly affects the raw wastewater salinity, while the chloride concentration in the aquifer is set by the spatially distributed laboratory results for the year 2013.

Fig. 8. The simulated chloride concentration (mg/l) from the continuous infiltration for the SAT system infiltration basin (A) After 365 days and (B) After 7300 days.

The results indicate that the infiltrated water is mixed with the aquifer water after 1 year beneath the recharge area and spreads outward becoming more diluted in the surrounding area (see Fig. 8). The geo-membrane system has a minimum effect on groundwater in case of chloride concentration, so that it can be neglected when compared with the SAT system.

In term of output water quality from the two systems, the simulated water quality results for the SAT system can be summarized as: total suspended solids (TSS) < 10 mg/l, chemical oxygen demand

(COD) < 10 mg/l, biological oxygen demand (BOD) < 10 mg/l. The laboratory results for output water quality from geo-membrane sand filtration can be summarized as, the average TSS 14.5 mg/l, average BOD 28.2 mg/l and the average COD 143.2 mg/l, however the main input water quality for both systems can be summarized as: TSS 83 mg/l, BOD 66 mg/l and COD 188 mg/l, these values are investigated and validated in [15]. Treatment efficiency and parameters of the two stages in the geo-membrane system are illustrated in Table 2 as averaged values for the monitored parameters.

Fig. 9. The simulated tracer concentration (%) from the continuous infiltration for the SAT system infiltration basin (A) After 365 days and (B) After 7300 days.

In terms of economic comparison, geo-membrane sand filtration seems more feasible since the power requirement for sand filtration is less than the recovery wells in the SAT system. The specific power cost for geo-membrane sand filtration is 0.012\$/m compared with 0.147\$/m³ in the SAT system, i.e. almost 10 times more. However, the capital cost for the geo-membrane infrastructure is more than the capital cost for the SAT system itself. Finally, the surveying data was analyzed and it shows that both options are

accepted by the surrounding community, although the SAT system is preferred (see Table 3).

The hierarchy grey relational analysis and Comparison Matrix collects and summarise all the discussed data in the row data hierarchy grey relational data matrix, see Table 3. The hierarchy grey relational analysis is calculated in Table 4 and the results show that the integrated grey relational grade is 0.3276 for the sand filter and 0.2546 for SAT system. The results indicate that for this particular

case study the sand filter system has the advantage over the SAT system. The hierarchy grey relational analysis method shows the strong ability to provide the decision makers with the most feasible options in the wastewater industry in the developing countries as this case study or in the developed countries, which discussed in [19,35].

4. Conclusions

The wastewater post-treatment alternative options selection is a multiple objective decision-making process. Complexity, uncertainty and hierarchy are the most important characteristics. An innovative hierarchy grey relational analysis and comparison matrix were performed in this study to compare and evaluate the two available post treatment options in the Gaza city WWTP. The presented hierarchical method is sensitive to the number of comparison levels and the assigned weights for each component. The data for the comparison process comes from the simulation procedure for the effects of SAT system and full-scale project for the geo-membrane sand filtration system. This method allows for more accuracy with respect to the actual characteristics of the options.

The hierarchy grey relational analysis using simulation process, the full-scale project and the laboratory analysis shows that the sand filtration has an advantage on SAT system based on environmental, operational and socioeconomic aspects.

Although, the post-treated effluent water quality for the SAT system is better than the sand filtration system, it can be concluded that the socioeconomic aspects has an crucial role on influencing the integrated grey relational grade for geo-membrane sand filtration system and giving it an advantage on SAT system.

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References

- [1] C.D.T. Abel, Soil Aquifer Treatment: Assessment and Applicability of Primary Effluent Reuse in Developing Countries, UNESCO-IHE, Institute for Water Education, 2014.
- [2] T.H. Abushbak, An Experimental and Modeling Investigation of Soil Aquifer Treatment: System: Gaza City Case : PhD Dissertation, KVL, Department of Agricultural Sciences, 2004.
- [3] A. Adetola, O. Benedicta, Poverty and preference for improved solid waste management attributes in Delta-State, Nigeria, *J. Rural Econ. Dev.* (2015) 19.
- [4] A.M. Aish, Simulation of groundwater mound resulting from proposed artificial recharge of treated sewage effluent case study—Gaza waste water treatment plant, Palestine, *Geolgia Croatica* 63 (2010) 67–73.
- [5] A. Al-Yaqubi, A. Aliwi, Z. Mimi, Bridging the domestic water demand gap in Gaza Strip-Palestine, *Water Int.* 32 (2007) 219–229.
- [6] M.P. Alderson, A.B. dos Santos, C.R. Mota Filho, Reliability analysis of low-cost, full-scale domestic wastewater treatment plants for reuse in aquaculture and agriculture, *Ecol. Eng.* 82 (2015) 6–14.
- [7] M. Beynon, DS/AHP method: a mathematical analysis, including an understanding of uncertainty, *Eur. J. Op. Res.* 140 (2002) 148–164.
- [8] E. Birol, P. Koundouri, Y. Kountouris, Evaluating farmers' preferences for wastewater: quantity and quality aspects, *Int. J. Water* 4 (2008) 69–86.
- [9] M. Bottero, E. Comino, V. Riggio, Application of the analytic hierarchy process and the analytic network process for the assessment of different wastewater treatment systems, *Environ. Model. Softw.* 26 (2011) 1211–1224.
- [10] W. Chiang, W. Kinzelbach, Processing Modflow (PM), Pre-and Postprocessors for the Simulation of Flow and Contaminant Transport in Groundwater System with MODFLOW, MODPATH and MT3D, Distributed by Scientific Software Group, Washington, DC, 1993.
- [11] A. de Bruin, R. Pateman, J. Barron, et al., Setting up agricultural water management interventions—learning from successful case studies in the Volta and Limpopo river basins, *Water Res. Rural Dev.* (2015).
- [12] X. Garcia, D. Pargament, Reusing wastewater to cope with water scarcity: economic, social and environmental considerations for decision-making, *Res. Conserv. Recycl.* 101 (2015) 154–166.
- [13] S.S. Gharbia, A. Aish, F. Pilla, Impacts of climate change on a spatially distributed water balance in the Gaza Strip, Palestine, *J. Environ. Earth Sci.* 5 (2015) 76–91.
- [14] S.S. Gharbia, A. Aish, F. Pilla, Modelling potential impacts of climate change on groundwater of the Gaza coastal aquifer from ensemble of global climate model projections, *Civil Environ. Res.* 7 (2015) 44–60.
- [15] S.S. Gharbia, F. Pilla, A.S. Gharbia, Correlating biochemical and chemical oxygen demand of influents and effluents—a case study of selected wastewater treatment plants in the Gaza Strip, Palestine, XVth IWRA World Water Congress, At Edinburgh, Scotland (2015).
- [16] M.A. Hanjra, J. Blackwell, G. Carr, et al., Wastewater irrigation and environmental health: implications for water governance and public policy, *Int. J. Hyg. Environ. Health* 215 (2012) 255–269.
- [17] M.G. Healy, M. Rodgers, J. Mulqueen, Treatment of dairy wastewater using constructed wetlands and intermittent sand filters, *Bioresour. Technol.* 98 (2007) 2268–2281.
- [18] M. Jeuland, Challenges to wastewater reuse in the Middle East and North Africa, *Middle East Dev. J.* (2015) 1–25.
- [19] A. Karimi, N. Mehrdadi, S. Hashemian, et al., Selection of wastewater treatment process based on the analytical hierarchy process and fuzzy analytical hierarchy process methods, *Int. J. Environ. Sci. Technol.* 8 (2011) 267–280.
- [20] Y. Mogheir, J. De Lima, V. Singh, Characterizing the spatial variability of groundwater quality using the entropy theory: II. Case study from Gaza Strip, *Hydrol. Process.* 18 (2004) 2579–2590.
- [21] Y. Mogheir, V. Singh, J. de Lima, Spatial assessment and redesign of a groundwater quality monitoring network using entropy theory, Gaza Strip, Palestine, *Hydrogeol. J.* 14 (2006) 700–712.
- [22] G. Oron, C. Campos, L. Gillerman, et al., Wastewater treatment, renovation and reuse for agricultural irrigation in small communities, *Agric. Water Manag.* 38 (1999) 223–234.
- [23] D. Pedretti, M. Barahona-Palomo, D. Bolster, et al., A quick and inexpensive method to quantify spatially variable infiltration capacity for artificial recharge ponds using photographic images, *J. Hydrol.* 430 (2012) 118–126.
- [24] M. Qadir, B.R. Sharma, A. Bruggeman, et al., Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries, *Agric. Water Manag.* 87 (2007) 2–22.
- [25] K. Qahman, A. Larabi, Evaluation and numerical modeling of seawater intrusion in the Gaza aquifer (Palestine), *Hydrogeol. J.* 14 (2006) 713–728.
- [26] K. Qahman, Y. Zhou, Monitoring of Seawater Intrusion in the Gaza Strip, Palestine, IHE, 1998.
- [27] S. Raja, H.M.N. Cheema, S. Babar, et al., Socio-economic background of wastewater irrigation and bioaccumulation of heavy metals in crops and vegetables, *Agric. Water Manag.* 158 (2015) 26–34.
- [28] T.L. Saaty, How to make a decision: the analytic hierarchy process, *Eur. J. Op. Res.* 48 (1990) 9–26.
- [29] B. Shomar, A. Dare, Ten key research issues for integrated and sustainable wastewater reuse in the Middle East, *Environ. Sci. Pollut. Res.* 22 (2015) 5699–5710.
- [30] B. Shomar, G. Müller, A. Yahya, Geochemical features of topsoils in the Gaza Strip: natural occurrence and anthropogenic inputs, *Environ. Res.* 98 (2005) 372–382.
- [31] E. Triantaphyllou, Multi-criteria Decision Making Methods: A Comparative Study, Springer Science & Business Media, 2013.
- [32] E. Weinthal, A. Vengosh, A. Marei, et al., The water crisis in the Gaza Strip: prospects for resolution, *Groundwater* 43 (2005) 653–660.
- [33] D. Wichelns, M. Qadir, Policy and Institutional Determinants of Wastewater Use in Agriculture, Wastewater, Springer, 2015, pp. 93–112.
- [34] C.-C. Yang, B.-S. Chen, Supplier selection using combined analytical hierarchy process and grey relational analysis, *J. Manuf. Technol. Manag.* 17 (2006) 926–941.
- [35] G. Zeng, R. Jiang, G. Huang, et al., Optimization of wastewater treatment alternative selection by hierarchy grey relational analysis, *J. Environ. Manag.* 82 (2007) 250–259.
- [36] I. Zucker, H. Mamane, H. Cikurel, et al., A hybrid process of biofiltration of secondary effluent followed by ozonation and short soil aquifer treatment for water reuse, *Water Res.* 84 (2015) 315–322.