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Comprehensive Decision Approach for Sustainable Wastewater Reuse using Multicriteria Decision Analysis-GIS

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Abstract— The evolving water scarcity in the Gaza Strip adds extra pressure on the limited available groundwater source and leads to water quality deterioration. There is a high need for sustainable nonconventional water resource. Wastewater reuse (WWR) is one of the main water strategies in the Gaza Strip due to the increase amount of generated wastewater and the rehabilitation of treatment facilities. However, WWR can generate negative impacts to the ecological and the socio- economical system once it has been poorly applied. The current study investigates the most sustainable WWR schemes by accounting for the impacts of WWR based on real field study. Multicriteria analysis and experts' judgment were used to identify the impacts of WWR and to prioritise the severity of these impacts, respectively. WWR impacts were weighed using multi criteria analysis DEFINITE software according to their relative importance. Results indicated that public health and cost of treatment are of the most concern. Spatial analysis using geographic information system (GIS 9.2) was conducted to investigate the areas with high potential for WWR over the Gaza Strip based on the multicriteria results. Resulted map showed that Gaza southern area has the high potential for WWR with the least possible generated impacts..

Index Terms— Gaza Strip, GIS, Multi-criteria, analysis,wastewater, reuse.

I INTRODUCTION

Groundwater is the only fresh water source in the Gaza Strip. The groundwater is highly overexploited and is heavily contaminated due to agricultural activities and seawater intrusion (Qahman et al. 2009; Al-juaidi et al. 2011; Al-Najar and Ashour, 2013). Average annual water deficit in the Gaza Strip is estimated by 60-70 Mm3 (PWA 2013). Recent reports showed that the groundwater aquifer in the Gaza Strip will become unusable by 2020 where the deterioration will become irreversible by 2020 (UNRWA 2012). The expanding urbanization, the lack of sufficient water harvesting facilities and the poor aquifer recharge have worsened the water problem. Current water demand is estimated by 180 Mm3, 70% of which is being consumed by the agriculture sector (PWA, 2013).

In fact, this sector accounts for the high nitrate concentrations in aquifer resulting from the intensive use of fertilizers and pesticides under low recharge conditions. The average nitrate concentration in agricultural areas is five times more than the standard limits of WHO (50 mg/l). Moreover, the over pumping from agricultural illegal wells intensified accelerated the sea water intrusion and resulted in high chloride levels (average of 800 mg/l) (Al Najar, 2011). Water resource planners therefore, have to find non-conventional alternate sources of water to bridge the deficits (Al-Agha & Mortaja 2005). Possible management options include the use of treated wastewater (TWW) and desalination are at the forefront of water management plans (Al-yaqubi et al. 2007; Al-juaidi et al. 2011). There is a high potential for WWR due to the increased generated wastewater quantities. (Afifi, 2006) estimated that about 92Mm3 of wastewater will be generated in Gaza strip by year 2020. This amount- if properly used- can provide adequate amount for the agricultural sector and save the aquifer from further deterioration. The lack of proper wastewater collection system creates the need to dispose partially treated wastewater to the open lands and hence significant environmental pollution and public health concerns are encountered. WWR not only can reduce the water deficit in the Gaza Strip, but it also can minimize the environmental deterioration which is one of the main aspects considered by the policy makers in the Gaza Strip (Al-Juaidi et al. 2010). However, WWR can generate negative impacts due to the different governing conditions and the current strategies for WWR (Anane et al, 2012). To our knowledge, there is no specific designed framework that accounts for all the possible generated impact. In addition, there is a knowledge gap in investigating the impact of WWR in spatial scale based on criteria analysis. Al Juaidi et al. (2010) studied the optimisation and the decision analysis of the proper allocation of the fresh and the WWR based on the crop types with cost effective study (Al-Juaidi et al. 2010). However, the study only accounts for cost-benefit criteria without accounting for the social and ecological impacts.

The impacts of WWR are site specific and depend on water quality, crop, soil types and other factors (Abunada & Nassar 2014). Impacts of WWR have to be accounted for and the severity of these impacts has to be addressed. The relative importance and weights for these impacts have also to be determined.

Several MCA techniques have been used to identify the most suitable locations for wastewater reuse such as ELECTRE, PROMETHEE, AHP, TOPSIS, AIM, etc. (Behzadian et al, 2010; Conté et al., 2008; Zhong-Wu et al., 2006). However, only few have integrated into GIS [Al-Adamat et al., 2010; (Kallali et al., 2007). Analytic Hierarchy Process (AHP) was established by Thomas Lorie Saaty in 1970s. AHP was used to prioritise the different decision alternatives regarding to the WWR using pair-wise comparisons (Anane et al., 2012).

The current works aims at defining the relative importance of the possible generated impacts of WWR using expert judgments. The MCA is used to prioritise these impacts and to account for the possible influences by either assigning positive or negative effects. Based on that, a spatial analysis using GIS is conducted to identify the most suitable areas for WWR. For this reason, multi criteria analysis (MCA) and spatial analysis GIS tool were integrated to evaluate these impacts based on real judgments.

II Methodology

Multi-criteria analysis (MCA)

The MCA evaluates the problem under consideration in term of evaluation trade-off matrix. Matrix columns represent the different alternatives under consideration while rows represent the evaluation criteria where these alternatives have their impacts. Decision of Finite Set of Alternative (DEFININIT) software developed by institute of environmental studies of VU Universitywas used to conduct the MCA analysis. In DEFINITE, the matrix elements are quantifying the performance of each alternative with respect to the criterion based on the following:

1. i (i=1..I) represents the alternatives and j (j=1..J) represents the criteria. Sji denote the effect of alternative i according to criterion j. The matrix S (J x I) includes all data about the performance of the desired alternatives and is called the effects table.
2. The priorities assigned to the decision criteria are expressed in weights wj (j=1,..j). Theses weights were assigned by experts judgment and they are site specific based on the ecological and socio-economic conditions. The elements weight reflects its importance. The summation of weights within the criteria equals hundred in order to accounting for the relative weight of elements within the same criteria. Similarly, the relative weights of the criteria were assigned and the summation of the criteria weights equals hundred.

The current study considered three main alternatives to simulate three different wastewater treatment conditions. It represents the case of no reuse, the reuse under current situation with partially treated wastewater and the reuse under improved treatment. These cases were expressed as no project, current situation and extended treatment scenarios, respectively.

The MCA contained nine main criteria: total cost, crop production, public health, soil contamination, groundwater contamination, groundwater recharge, ecology, social impacts and environmental impacts as shown in Table 1. To our knowledge, literature has not reported such a comprehensive criteria where all possible WWR impacts were combined and evaluated in one analysis.

The main criteria were subdivided into sub elements (i.e. cost was subdivided into cost of treatment and the resulted cost savings from no-use of fertilizers).

The weight for main and sub criteria were assigned by thirty eight experts (responded positively) from the field of water and wastewater in the Gaza Strip represented the senior level at their institutions. Experts represented wide spectrum of different institutions including academics, professionals, consultants, industry, governmental and nongovernmental organizations. There was high agreement between the experts and the analysis showed good agreement among the scores assigned to single criteria where the standard deviation between the highest and the lowest weight was ± 0.07.

Following the determination of the weights and the values of the elements and the criteria, all effect scores were standardized. The scores of the main alternatives were calculated by multiplying the standardized effect scores times their assigned weights. These weights are then used for the following work with GIS, where criteria and sub-criteria are represented by spatial data based on the concept of the impact for each.

Criteria can be presented by data grid, where every single cell has a standardized value according to its influence and depending on the status of wastewater source (i.e. treatment condition). Each grid is assigned a weight based on those identified by stakeholders for the first part. Generally, MCA includes main steps starting from problem definition to decision taking and final conclusion as shown in Figure 1.

Through the current study, MCA has been carried out according to the following steps:

Definition of problem; The analysis aims at clarifying the significant impacts of WWR under different scenarios. Then the process will be extended to specify the best areas suitable for WWR for irrigation using GIS and Spatial Analysis.

Involvement of stakeholders; Stakeholders from different sectors that can be affected by WWR and can be part of the planning and decision making process are invited to contribute. This included decision makers, ministries, Palestinian Water Authority, universities, municipalities, private sector, international and nongovernmental organizations, and others. In the current study, a sample of 38 experts in water and wastewater sector including 16 academics, 14 managerial staff from different institutions concerning with water sector, 3 professionals form nongovernmental organizations and 5 technicians, was consulted to set up the main alternatives and to address the possible generated impacts.

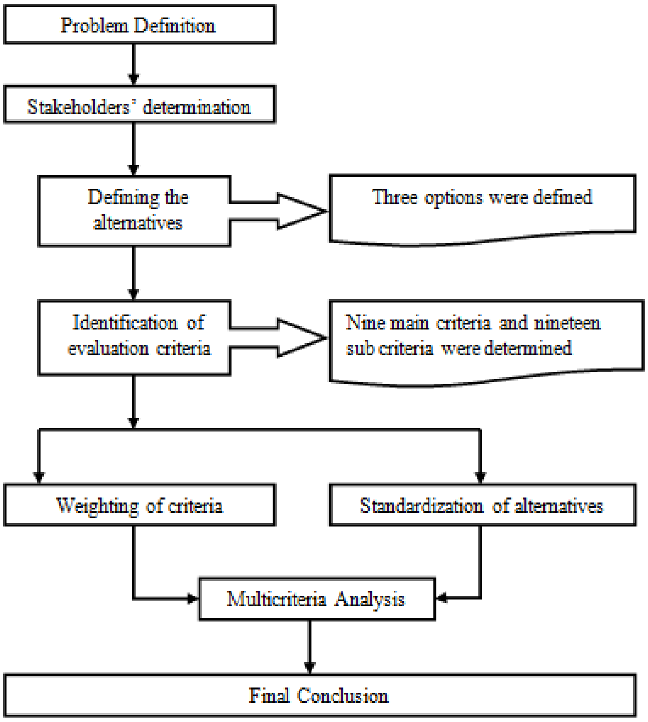

Figure 1 Schematic diagram showing main steps of multi-criteria analysis for Decision Analysis (MCDA)

Definition of options; Three options were identified based on the current strategies for WWT. The first option is (to do nothing), the second is to use the current TWW, and the third is to establish reuse but with extended treatment that enhances current TWW quality. These scenarios actually represent the existing situation and planned strategies for WWT in Gaza Strip. Identification of Criteria; Stakeholders were provided with an elongated list of possible impacts on different themes. The stakeholders have eliminated the trivial items and highlighted or listed new items. Working close to all of them helped building a decision hierarchy structure of nine criteria with nineteen sub-criteria as listed in Table 1.

Weighting of Criteria; stakeholders were consulted once again to rank the criteria and sub-criteria according to its significance out of 100 as shown in Table 1 based on their own judgments. This represented the corner stone of the MCA.

Standardization of Alternatives; in this process, WWR impacts for each of the three alternatives defined in step 3 are set to a common domain of measurement. This domain ranged from extreme negative (---) to extreme positive (+++) representing the value of 0 to 1. This means that the values scaled up to 7 including the zero value which represented the neutral case or no sense. The impact ranged from large negative effect as 0 to large positive effect 1. The standardization of options is presented in Table 1.

The main unique feature of DEFINITE is that it can systematically leads the researcher through a number of rounds of an interactive assessment circles and uses an optimization approach to integrate all information provided by the experts to a full set of value functions [Fahmy et al., 2001].

TABLE 1

Main criteria and sub-criteria with the assigned weights under different reuse scenarios with its standardized values

						Standardization		
NO.	Criteria	Weight Level 1	Sub-criteria	Weight Level 2	Total Weight	No Projects	Current Situation	Extended Treatment
1	Total Cost	0.11	Cost of treatment	1.00	0.110	0.50	0.33	0.00
2	Crop Production	0.13	Fertilizer Savings	0.50	0.065	1.00	0.83	0.67
			Crop Yield	0.50	0.065	0.33	0.67	0.50
3	Public Health	0.13	Morbidity	0.50	0.065	0.00	0.33	0.83
			Mortality	0.50	0.065	0.00	0.33	0.83
4	Soil Contamination	0.13	Soil Salinity	0.38	0.049	0.50	0.50	0.50
			Land Value	0.30	0.039	0.17	0.33	0.33
			Reclamation	0.32	0.042	0.33	0.50	0.50
5	Ground water Contamination	0.13	Nitrate	0.50	0.065	0.00	0.33	0.50
			Pathogens	0.50	0.065	0.00	0.17	0.33
6	Ground water Recharge	0.11	Cost of domestic water supply saved by WWR	0.57	0.063	0.67	0.83	1.00
			Cost/m^3 of irrigation supply	0.43	0.047	1.00	1.00	1.00
7	Ecology	0.06	Biodiversity	0.52	0.031	0.00	0.17	0.33
			Aquatic life loss	0.48	0.029	0.17	0.33	0.50
8	Social Impacts	0.12	General Concerns	0.30	0.036	0.00	0.17	0.33
			Social Concerns	0.38	0.046	0.00	0.67	0.83
			Natural resources concerns	0.32	0.038	0.00	0.17	0.33
9	Environmental Impacts	0.08	Environmental quality	0.50	0.040	0.00	0.17	0.33
			quality of life	0.50	0.040	0.00	0.17	0.33

III Criteria

The main evaluation criteria of the generated impacts included the following evaluation effects:

Total Cost: WWR has different economical implications in terms of cost and benefit. Total cost includes the cost of developing the treatment facilities to allow for specific effluent quality, operation, maintenance and supplying of the treated wastewater to the desired locations. To determine the development cost of a treatment facility, fixed treatment capacity was assumed with. This allows to calculate the cost per cubic meter and to eliminate scale of economy where the calculations were consistent. The benefits are generated from the reduction of fertilizers use and the possible increase in crop production as a result of wastewater reuse. This cost criterion is expressed in GIS by a constant layer for construction and operation and maintenance costs. Supplying cost is presented as a function of the distance to the wastewater treatment plant. The weights of sub-criteria are 0.5 for both of construction and operation and maintenance.

Crop Production: Organic matter provides main nutrients for crops and enhances the crop production. This results in cost savings due to limited addition of fertilizers and enhances the crop yield. Obviously, this will be converted into benefit. Fertilizers savings was calculated by multiplying the annual crop water quantities needed times the concentration of nutrients under each alternative. No project for example provides the greater amount of nutrients with zero need to any fertilizers.

For GIS, this criterion was expressed by the crop type. Crop rotation may become necessary in case of WWR. So, a GIS layer was prepared standardizing areas dedicated for non restricted irrigation schemes and being subjected to "large negative effect".

Public Health: Public health was evaluated based on the level of impacts that the contaminants can affect the human health and to what extent the resulted impacts can spread through. This is highly dependent on the irrigation method and crops type. However, this criterion has less risk under extended treatment as viewed by stakeholders. Therefore, this criterion was expressed by the mobility and morbidity rates. This was expressed in the GIS in terms of the distance of the reuse areas from current residential areas.

Soil Contamination: The sub-criteria identified under this category are the impact on soil erosion and contamination, degradation of land value, and the potential for reclamation of soil. It is highly influenced by the soil type, irrigation method and on irrigated water quality. The level of treatment is a key factor in determining the severity of this criterion.

Groundwater Contamination: Wastewater constituents leaching to both soil and aquifer was expressed by groundwater contamination. Pathogenic contamination and soil build up nitrate pollution are the main contamination events. This effect is crucial in case of shallow groundwater. GIS indicator was expressed in terms of the depth of water table and soil type. In GIS, the deeper the water table, the more suitable option is produced. Sandy soil has more capacity to leach contaminants beyond the root zone and results in severe impacts.

Groundwater Recharge: WWR provides an alternative water source and release the stress on the existing water resources. To some extent, this can be viewed as a groundwater recharge based on aquifer depth and soil type and other parameters where the saving amounts worked as new charge rather than abstraction. This was expressed in terms of the generated savings from water abstraction and the benefit of unlimited water resource. Therefore this effect was presented by the GIS in terms of distance from the fresh water resource where the cost of irrigation depends on the location of water well.

Ecology: Ecology was expressed in terms of the impact on the biodiversity and the aquatic life. This effect was viewed in terms of the distance between the disposal sites of TWW and the residential areas. It also was expressed as how much the effect on the aquatic life will be in case of disposing the effluent into the sea and the generated benefits from reusing the wastewater for agricultural purposes.

Environmental and social Impacts: The impact on the overall environment quality was expressed as a measure of the environmental quality and quality of life. This was presented as a constant grid all over Gaza Strip assuming uniform effect over the Gaza Strip under same treatment condition with better environmental quality under extended scenario. The social impact was based on previous studies and assumed public acceptance for the WWR according to the weighting and standardization specified in Table 1.

IV Results and discussion

According to the MCA results (Figure 2), the option of extended wastewater treatment seems to be the most feasible option. Although, this option does not win in terms of total cost which is a trade of different generated costs, it stands as the best option for all other aspects. It also comes second in crop production effect as more nutrients can be provided by the current situation. [Fahmy et al., 2001] indicated that MCA analysis may lead that the most feasible alternative may not get the high scores in every single evaluation effect, but its overall performance is much better than all the others.

The significance of the extended treatment alternative appears clearly in the case of public health which is one of the top criteria that was under the concern of stakeholders. High variation is presented between the current and the extended options in this aspect as it is believed that current WW quality is the main reason for the visible environmental deterioration which results in bad odor and other stuff. One interesting note is related to the effect on crop production, where the current quality of wastewater is believed to save more nutrient than extended treatment alternative, however, it seems that this option which mainly reflects one of the cost themes has nothing compared with other critical aspects, such as public health and GW contamination. This might be also due to the fact that extended treatment option may provide the required nutrients for some certain crops. Hence, the gain from the fertilizers saving compared with other criteria especially public health is minor. It was obvious that do nothing option, is the worst case that can be considered. It has very negative impact in terms of public health, environmental and social impacts. This confirms that there is a high demand for WWR especially regarding these concerns.

In Figure 3, it can be noticed that spatial analysis has shown interesting findings regarding the difference in suitability of land for irrigation with TWW under the two conditions (current and extended option). The extending urbanization is limiting the area suitable for agriculture in general. Giving that social impact is higher on those who live next to the irrigated lands, additional zone of less suitable lands for WWR got formed as a buffer around the urbanized areas. This can be seen clearly as the white colour in both maps. Areas where TWW can be used are concentrated in the eastern parts of Gaza Strip. This might be due the fact the water table is slightly deeper than other places and due to the fact that these areas still raw in terms of urbanization. These results agree with those obtained by [Sogreah, 1999].

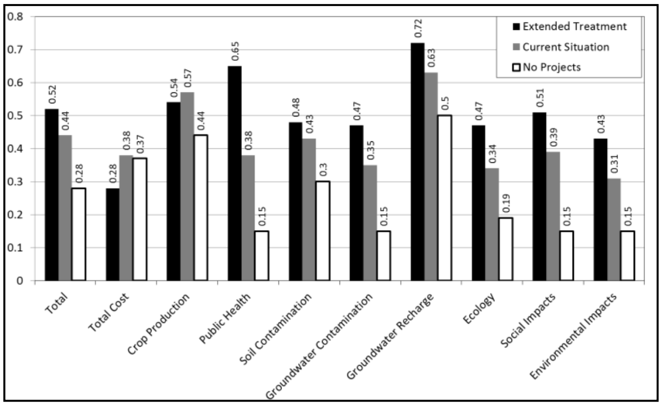

Figure 2 Results of MCA

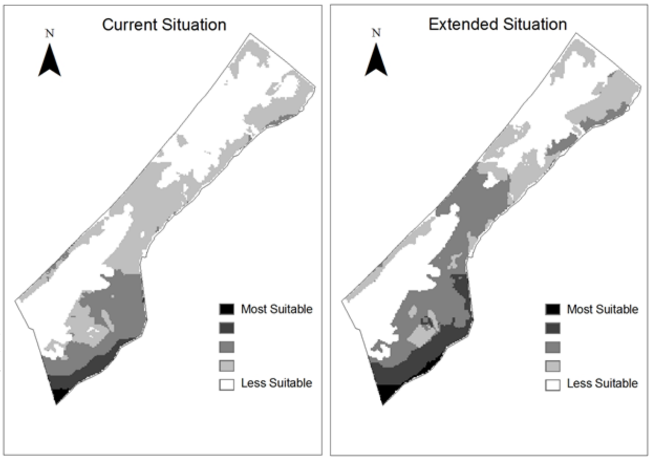

Figure 3 Suitable Areas for Irrigation with TWW under current condition of WWTPs and extended condition

The extent of the suitable area for irrigation doesn't change significantly with the new planned extended WWT option. This is logically feasible since none of the spatial characteristics of spatial data or their attributes are changed. However, the change that the extended treatment systems are going to enhance the suitability of land can be visibly noticed. This significant enhancement can be explained by the criteria measures described earlier; however, spatial factors contributed this result significantly. The new location of WWTPs falls on the eastern regions, which results in significant minimization of transportation costs, as well as minimization of impact on social life and public health.

V Conclusions

The reuse of treated wastewater for agricultural purposes is a good option accounting for new water resource. The need for the nonconventional water source is of great concern especially in arid areas. Generated impacts of WWR were determined based on literature and the impacts relative importance was assigned based on the level of impacts and frequency. This study indicated that public health and cost are of great concern from the expert judgments perspective. The decision making process using MCA and GIS showed that more care has to be taken in selecting the areas of WWR. The decision has to account for the crop type, soil type, water quality and the geographic location. The southern part of the Gaza Strip seems to be most suitable and verifying the whole criteria for site selection. Under current conditions, it seems that extended treatment could provide the best WWR quality and hence increase the opportunity of WWR.

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