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EFFLUENT MANAGEMENT OF THE GAZA CENTRAL WASTEWATER TREATMENT PLANT : ASSUMPTIONS AND IMPLICATIONS

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ABSTRACT

Irrigated crop production in Gaza is constrained by poor water quality with salinity and chloride concentration above the tolerance of many crops resulting in restricted yields. Gaza Central Wastewater is designed to treat a wastewater flow up to 115,700 m3/day with a design horizon of 2015, and produces an effluent quality (BOD=20 mg/l; TSS=30 mg/l; TKN=25 mg/l). Three main disposal options are proposed: use in irrigation, aquifer recharge and disposal to Wadi Gaza; this paper presents these options, and propose the most feasible one.

Predicted effluent quality is suitable for irrigation of a wide range of crops, with only marginal reduction in potential yield provided that the irrigation with leaching regime is appropriate to control soil salinity. The most appropriate effluent reuse strategy should be dependent upon direct supply for crop irrigation and the surplus recharged to the aquifer.

Key words: *Irrigation, recharge, strategy, effluent, treatment*

INTRODUCTION

The Gaza Strip suffers severe shortage in water supply and sanitation due to its location, confinement, high population and semi-arid coastal climate. Groundwater provides the potable water supply for the human consumption and crops irrigation (Afifi, 2006). It is only recharged by rainfall that percolates through the soil for subsequent natural storage in aquifers.

In general, the extraction of groundwater exceeds the aquifer recharge rate. The total abstraction of the groundwater in Gaza Governorates in 2007 is estimated to be 170 Mm^3/year (Hamdan et. al, 2007), the water balance record reveals a deficit of about 50 Mm^3/year. Agriculture consumes around two thirds of groundwater pumped through more than 4600 wells located overall Gaza Governorates (Al-Najar, 2007). As a result, the groundwater level is falling and chloride concentration is increasing, making water quality increasingly marginal and is continuously being over-exploited (Naciri, 2001).

Agriculture in the Gaza Strip is an important contributor to Palestinian gross domestic product (25%) providing employment and export products as well as producing foodstuff for the local market (PCBS, 2006). Agriculture relies heavily on groundwater for irrigation but over-abstraction has degraded water quality which affects crop production. However, the agricultural potential of the Gaza Strip is constrained by a number of factors, including:

- Lowering of groundwater table by excessive pumping results in reducing water quality which affect crop production as well as municipal water supplies; (Tubail et. al, 2004).
- The sensitivity of the most economically important crops to the poor groundwater quality used for irrigation; (Al-Najar, 2007)
- All fertilizers and most of the animal manure used for crop production are imported from Israel; (Nassar et. al., 2009a)
- Destruction of productive land by the Israelis (PCBS, 2006).

As a result, irrigated crop production throughout much of Gaza is constrained by poor water quality with salinity and chloride concentration above the tolerance of many crops resulting in restricted yields. Most countries in the Mediterranean and the Middle East regions have adopted a policy to recycle treated wastewater for other uses, principally agriculture, provided that the effluent is chemically and microbiologically suitable, and conforms to quality standards (CAMP, 2000). The recycling of treated effluent can provide significant social, economical and environmental benefits, particularly in arid lands where water has always been a scarce resource (Nassar et. al, 2009c).

Reused wastewater in agriculture has been recognized as an essential component in the management strategy for water shortage in the neighbouring countries (World Bank, 2004). In Gaza Strip, such scheme of ensuring additional water supply is gaining attention in developing strategies for planning of Palestinian water resources (Tubail et al., 2004, Nassar et. al, 2009b).

The Wastewater Master Plan for Gaza divides the region into three wastewater catchments areas; North, Central and South (Sogreah et. al., 1998). Each area will be served by new wastewater treatment plant (WWTP) that will replace the existing ones. These inevitable products of wastewater treatment are valuable agricultural resources, particularly in the context of Gaza, this will reduce the current reliance of farmers on groundwater for irrigation, therefore treatment and reuse of wastewater requires careful planning and management to ensure that appropriate quality standards are achieved and the maximum sustainable benefits are realized in the most economical manner.

Gaza Central Wastewater Treatment Plant is designed to serve the central area, covering the Governorates of Gaza City and the Middle Area, see Figure 1. The plant is designed to treat a wastewater flow up to 115,700 m^3/d with a design horizon of 2015 (PWA, 2004). Wastewater quality in the Gaza Strip has high concentration in terms of COD, BOD and TSS while heavy metals are trace due to limited industrial activities in the area, see Table 1.

Table 1 : Wastewater Quality in the Gaza Strip.

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Average
pH	6.9	6.69	7.65	6.98	8.18	7.28
EC µS/cm	3200	2760	2920	2600	1880	2670
TS mg/l	2430	2790	1840	2150	1840	2210
TKN mg/l	158	166	114	147	102	137
COD mg/l	1420	1487	712	975	1147	1148
BOD mg/l	634	648	362	481	578	541
Pb mg/l	0.009	0.00	0.00	0.00	0.14	0.03
Fe mg/l	1.6	1.78	1.46	0.53	6.06	2.29
Co mg/l	0.06	0.03	0.00	0.13	0.16	0.08
Cu mg/l	0	0.00	1.35	0.00	0.13	0.30
Hg mg/l	0.21	0.26	0.02	0.03	0.28	0.16
Zn mg/l	0.72	0.21	0.08	0.03	0.34	0.28
Cd mg/l	0.01	0.01	0.00	0.04	0.13	0.04

Source: (IUG/CDG/ONEP, 2002)

The central wastewater treatment plant will produce an effluent with acceptable quality (BOD=20 mg/l; TSS=30 mg/l; TKN=25 mg/l). faecal coli forms <1,000 MPN/100 ml; and helminthes <1/l (PWA, 2004). There are many effluent disposal options to such quantity, this paper presents the options, propose the most feasible one.

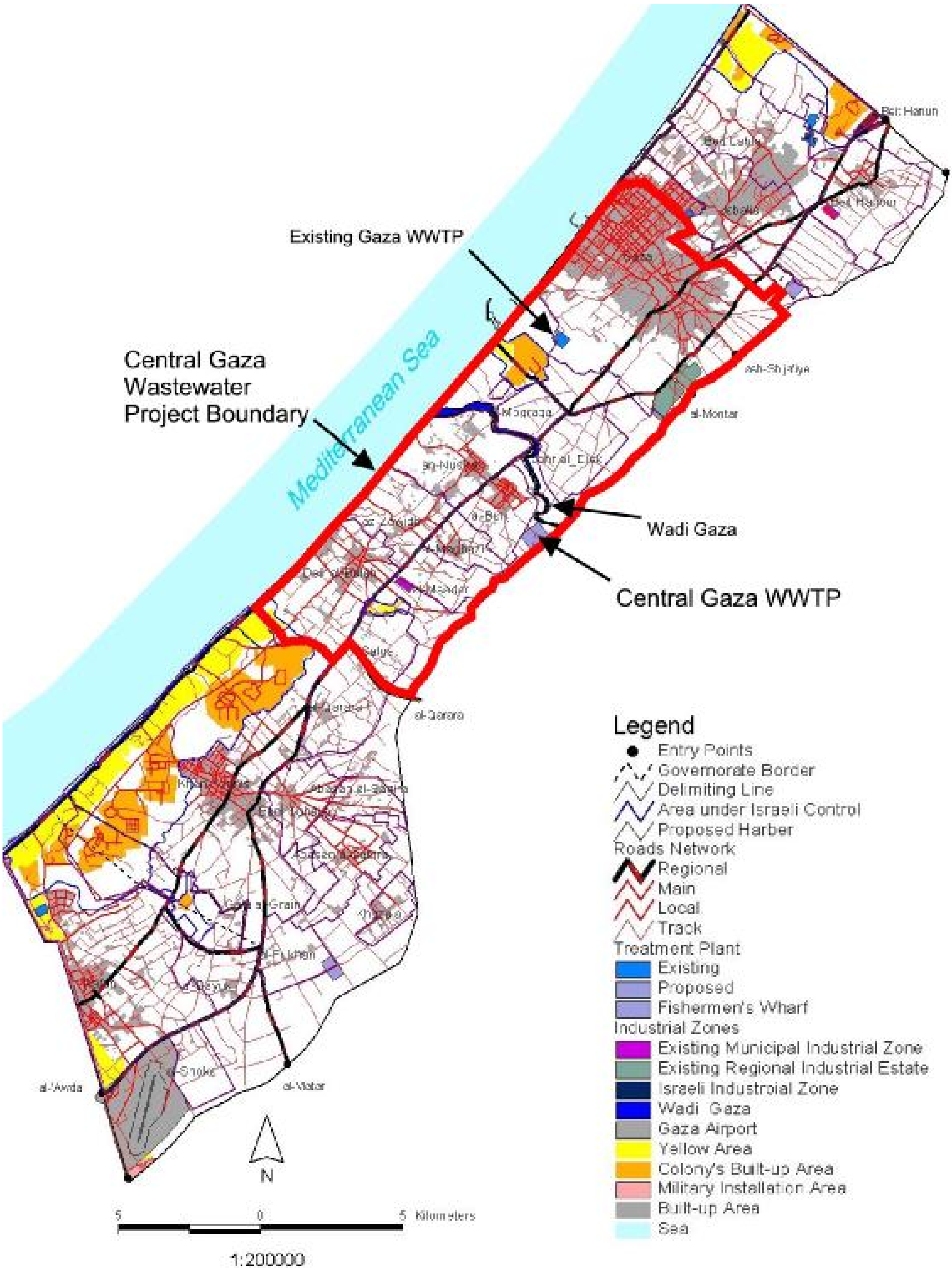

Fig 1: the location of wastewater treatment plants in the central area of the Gaza Strip.

MATERIAL AND METHODS

For Central Gaza WWTP, a range of conceptual options are screened for their suitability for the local conditions. The most feasible options are recognized as: Irrigation of agricultural crops, groundwater recharge, and discharge to Wadi Gaza. These main options were considered that could be operated in an integrated and flexible manner according to strategic water management decisions and demands for water.

Multi-criteria-technique is the adopted approach to identify and screen all of the potential variants. The main role of the technique is to deal with the difficulties that human decision-makers have been shown to have in handling large amounts of complex information in a consistent way. Multi Criteria techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities (MCA, 2009).

Seven options for treated effluent disposal has been evaluated using the following criteria: Environmental impact, option capacity, resource recovery, additional treatment cost, reuse cost, and reuse income :

1. Agricultural Irrigation

Irrigation of agricultural crops is the only feasible option for the direct reuse of treated effluent. The land currently under rain-fed cultivation and the availability of effluent will enable farmers to convert to irrigate and produce higher value crops. Existing irrigated crops that are currently suffering yield reductions like citrus due to the high salinity of the groundwater should recover some of their yield potential to more economic levels (MOA, 2005). Effluent from the existing Gaza WWTP is currently being used by farmers through pilot projects, principally for irrigation of citrus and forage crops. Despite the effluent is not treated to a high standard, initial results are encouraging as crop yields have improved significantly. Consequently, the technical ability of effluent to substitute groundwater is being proven and the acceptance of effluent by farmers is high.

According to a survey carried out by (Nassar, et. al, (2009c) to determine the views, practices and requirements of farmers in relation to effluent reuse the results are very positive with about 90% of farmers stating that they would be prepared to use and pay for effluent

2. Aquifer Recharge :

Recharge to aquifers is vital in order to maintain the groundwater and to replenish the discharge from the aquifer. When more water is removed from an aquifer than is replenished by recharge then the groundwater level falls and storage is depleted. The major advantages with regard to the local water resources are:

* Recovery of declining groundwater levels (quantitative aspect) and reduction of salinity of the aquifer from sea water intrusion and up-coning of saline groundwater (qualitative aspects);
* Rehabilitation of groundwater quality where effluent nitrate concentrations are smaller than existing concentrations (qualitative aspects).

Infiltration of treated wastewater (effluent) in ponds and basins undergoes natural processes termed as 'Soil Aquifer Treatment' (SAT). which lead to an amelioration of the treated wastewater. Contaminants are removed and/or attenuated, improving the quality of the effluent on its underground passage. Recharge is considered highly feasible in the Gaza Strip due to the general subsurface conditions comprising thick deposits of the Kurkar.

3. Discharge to Wadi Gaza

Discharge to Wadi Gaza has the potential to improve the environmental conditions and recreational potential of the area. Initially, the full flow of effluent should be discharged to Wadi Gaza and the adjacent wetlands. Even when reuse facilities are operational, the option to maintain a continuous or seasonal base-flow in Wadi Gaza remains available. However, discharge to Wadi Gaza without any subsequent recovery downstream for irrigation will result in loss of water to sea.

RESULTS AND DISCUSSION

Multi criteria has been adopted to assess the options, Table 2 determine the options that are likely to be the most suitable approaches for the effluent reuse. An initial qualitative multi-factor assessment of the individual components of these generic options is summarized in Table 3.

As shown in Table 2, the simplest option (Option 1) is to discharge the full flow of effluent to Wadi Gaza and this is the default option for the WWTP as designed. Wadi discharge will be necessary until a reuse project is established. This would have an immediate benefit for the Wadi Gaza environment; flushing out pollution from long-term sewage discharge. However, since the effluent would flow to sea, this option would result in a loss of a water resource.

Options 2, 3, 4 and 5 are based on direct effluent supply to farmers for restricted reuse via piped distribution networks. Option 2 would be the simplest option involving irrigation during the spring to autumn period and the surplus effluent during the winter period would be discharged to Wadi Gaza. Options 3, 4 and 5 would recharge the effluent surplus to irrigation needs, and during infiltration, further treatment of the effluent would take place. Option 3 would, in principle, supplement groundwater levels for subsequent extraction by existing wells and for control of saline intrusion. Option 4 would involve the use of recovery wells around the recharge sites and the recovered water pumped into the irrigation network to supplement flow in the summer period. Option 5 would be similar to Option 4 but the recovery wells would supply a separate distribution network for unrestricted irrigation (vegetable crops included). Options 3-5 would in effect provide temporary storage of effluent for increased supply during the irrigation season and thus the potential area for irrigation could be extended accordingly.

Options 6 and 7 would rely on the recharge the aquifer by effluent throughout the year, without or with recovery wells, respectively. Option 6 would be used for indirect groundwater supply and to control salt water intrusion. Also option 7 would in effect provide full soil aquifer treatment and the recovered water

Table 2: Description and Assumption of Conceptual Effluent Reuse Options.

Option No.	Option	Assumptions	Additional treatment implications
1	Discharge to Wadi Gaza(default option)	Initial operation of WWTP, no demand for reuse, Wadi improvement prioritized	None
2	Regional irrigation network, discharge surplus to Wadi Gaza	Established demand, restricted reuse, all wells and effluent supplies are metered	Disinfection (summer)
3	Regional irrigation network, recharge surplus	Established demand, direct (restricted) and indirect (unrestricted) farm supply, all wells and effluent supplies are metered, aquifer can take flow or partial discharge to wadi	Disinfection (summer) and Nitrogen removal (winter)
4	Regional irrigation network, recharge surplus to groundwater aquifer with recovery wells to network	Established demand, repump to supplement summer flow and expand command area, all wells and effluent supplies are metered,	Disinfection (summer)
5	Regional irrigation network, recharge surplus to groundwater aquifer with recovery wells to separate network	Established demand, separate network for unrestricted reuse, (expand command area), all wells and effluent supplies are metered,	Disinfection (summer)
6	Recharge full flow to groundwater aquifer	Aquifer can take flow (may require remote recharge ponds or partial discharge to wadi), indirect supply to farm wells, all wells are metered, unrestricted reuse	Nitrogen removal
7	Recharge full flow with recovery wells to regional irrigation network	Aquifer can take flow, all wells and effluent supplies are metered	None

would be supplied to farmers through a network for unrestricted reuse. The Previous options would in effect provide temporary storage of effluent for increased supply during the irrigation season and thus the potential area for irrigation could be extended accordingly.

Strategic Assumptions and Implications

The key assumptions are:

A. The quality of the treated effluent is suitable for the intended outlets in compliance with appropriate standards (feasible if WWTP operated as designed and standards are not set at highly precautionary values);

B. The cropping practices by farmers can be controlled to ensure that specific crops (mainly vegetables) are not grown where restricted reuse is necessary (this is unlikely at the current time);

C. Farmers will invest in efficient irrigation systems, according to the types of crops grown and in accordance with advice from the MOA (already achieved - majority of irrigation is by drip and sprinkler);

D. The coastal aquifer can accept large quantities of effluent by artificial recharge at appropriate locations that will

Table 3 : Qualitative Screening of Individual Components of General Effluent Reuse Options.

Component		Practicability	Environmental	Capacity	Resource recovery	Treatment cost (additional)		Reuse cost	Reuse income[2]
			Benefit	Impact[1]					
Discharge to Wadi Gaza									
Full flow	Default	H	M	L	H	0	0	0	0
Basal flow	Part flow, rest reused	H	L-M	L	H	0	H	0	0
Irrigation									
Irrigation surplus flow	No recharge, winter only	H	L	L	H	0	0	L	0
Recharge surplus flow	No irrigation and recharge rate is limited	H	L-M	L	H	0	H	L	0
Pumped network	Maximize area	H	H	L	H	H	H	H	H
Recharge[2]									
Full flow	Continuous[3]	H	H	L	M	H	H	H	M
Irrigation surplus	Seasonal[3]	H	H	L	H	H	H	M	M
Recovery wells (partial)	Winter recharge, summer pumping	H	H	L	H	H	M	H	H
Recovery wells (full)	Continuous recharge, summer pumping	H	H	L	H	H	L	H	H

Scoring: (0 = none; L = low; M = medium; H = high)

(1) Treatment to appropriate standard

(2) All wells and effluent supplies metered with tariff differential

(3) Aquifer has capacity (local or regional), or partial discharge to Wadi Gaza.

benefit groundwater levels and reduce saline intrusion (not quantified but is a reasonable presumption).

E. The farmer survey carried out has revealed a high willingness amongst farmers to use and pay for effluent (Nassar et.al., 2009c) but in practice this will only be achieved if:

i. The cost of treated effluent is lower than existing well supplies and the effluent has similar or better quality compared than the quality of existing wells.

ii. Effluent used for irrigation and recharge must meet with appropriate quality standards to ensure adequate protection of human health, agricultural production and the environment.

F. Aquifer recharge by treated effluent is widely regarded as an essential component of any effluent reuse strategy for Gaza to conserve water that cannot be used directly by agriculture. Recharge ponds are considered to be the most appropriate technique where the filtering effect of the unsaturated zone will further improve effluent quality.

Selection of Options and Potential Strategy Development

Table 3 compare between options based on several criteria mainly environmental impact, cost, resource recovery, additional treatment cost and reuses cost and income. Four scoring levels are used (0= no impact; L= low; M=medium; H = high). Clearly, Option 1 must be retained as this is the default option for the WWTP as currently designed, and will be required under any reuse scenario to take surplus flow, achieve environmental improvements in Wadi Gaza and as an emergency disposal option in the event of treatment or reuse system failure. This option has no additional cost or treatment implications but the economic and resource value of the effluent would ultimately be lost to sea.

All of the remaining options are considered potentially feasible, although some may be shown to be impracticable or uneconomic, but they can be considered as potential progressive steps in a development programme to maximizing effluent reuse and recharge.

The simplest initial reuse option is the direct supply of effluent for irrigation with effluent surplus to demand being discharged to wadi Gaza (Option 2). This would result in seasonally variable wadi flow, with full flow in mid-winter and no flow in mid-summer. Disinfection of the effluent used for irrigation would be required.

Full adoption of Option 3 would then involve seasonal irrigation and recharge of surplus effluent. Disinfection will be required for irrigation supplies and nitrogen removal is likely to be necessary for effluent recharged.

Option 4 would in effect use the aquifer as a temporary storage reservoir to supplement the direct effluent supply to farmers during the irrigation season, and thus substantially increase the area of land that may be irrigated at peak crop demand. However, this option would substantially increase investment and operating costs and there would need to be compelling technical reasons for developing this option. It may be argued that effluent disinfection and nitrogen removal would not be necessary as residual pathogens would be filtered out during recharge and there would minimal impact of nitrate concentrations in groundwater beyond the recovery zone. If this can be demonstrated to be the case, then this would represent a saving in operating costs of the WWTP.

Option 5, which is a development of Option 4, involves the establishment of a separate irrigation distribution network from recovered groundwater that would be suitable for unrestricted irrigation. This option may be appropriate where recharge facilities are remote from the direct effluent irrigation area.

The feasibility of Options 6 and 7, which involve recharge the aquifer by the full flow of effluent, depends on further evaluation and would require several recharge sites strategically located. Option 7 would in effect provide full soil aquifer treatment (SAT), but it would require a large number of recovery wells.

CONCLUSIONS AND RECOMMENDATIONS

A number of key conclusions and recommendations may be drawn for the development of effluent reuse for Central Gaza WWTP:

1- The most appropriate effluent reuse strategy should be dependent upon direct supply for crop irrigation and the surplus is recharged to the aquifer. Pumped recovery of recharged effluent is a feasible option but not recommended at the current time as this would increase costs and only a proportion of the effluent would be recovered.

2- Predicted effluent quality is suitable for irrigation of a wide range of crops, with only marginal reductions in potential yield provided that the irrigation (leaching) regime is appropriate to control soil salinity.

3- Aquifer recharge is considered highly feasible but the determination of the infiltration capacity is critical for verification of the suitability of specific sites and for sizing of ponds. For this, detailed site investigations are required which are beyond the scope of the current study.

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الملخص العربى

إدارة المياه فى محطة المعالجة المركزية فى قطاع غزة : الافتراضات والمتضمنات

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يعتبر إنتاج المحاصيل والتى تعتمد على الرى فى قطاع غزة محدوداً ويرجع ذلك إلى نوعية المياه والتى تزيد درجة ملوحتها عن قدرة تحمل المحاصيل، وقد أدى ذلك إلى إنخفاض فى إنتاجية المحاصيل، وقد صممت محطة المعالجة المركزية فى قطاع غرة لمعالجة ٧٠٠، ١١٥م٣ يومياً وذلك بحلول عام ٢٠١٥ بنوعية مناسبة (BOD = 20mg/l; TSS=30mg/l; TKN=25mg/l). وتوجد ثلاث اختيارات أساسية لاستخدام المياه المعالجة وهى : الرى المباشر للمحاصيل أو تغذية الخزان الجوفى، أو صب هذه المياه فى وادى غزة، ويناقش البحث المقدم الخيارات الثلاثة ويقترح أكثرها جدوى.

من المتوقع أن تناسب جودة المياه المعالجة مجموعة واسعة من المحاصيل ولكن مع إنخفاض محدود فى الإنتاج شريطة أن يكون الرى مقروناًباحتياجات الغسيل للحد من ملوحة التربة، وبناء على نتائج هذا البحث فإن أنسب إستراتيچية لإعادة إستخدام مياه الصرف الصحى المعالجة تتمثل فى الرى المباشر للمحاصيل، وحقن الفائض فى الخزان الجوفى.

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