Water reuse — an integral part of water resources management: Israel as a case study

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Received 13 June 2000; received in revised form 15 October 2000; accepted 13 November 2000

Abstract

Treated wastewater may be considered as a ‘new’ water resource, which can be added to the general water balance of a region. This ‘new’ source can substitute conventional water used for irrigation. Israel is presently reusing more than 65% of the total domestic sewage production of the country, and it is planned to reach more than 90% reuse during the next decade. This paper addresses the introduction of reclaimed wastewater in the water balance of the country, its contribution to the protection of the conventional water resources, the similarities and differences between water and wastewater resources management, and the economic benefits of wastewater reuse. © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

Wastewater reuse for agricultural irrigation is becoming a common and rapidly increasing practice in arid and semi-arid regions around the world, where treated wastewater serves as an extra source of water available for the rural sector. New projects for reclamation and reuse of wastewater are reported almost every year in countries all over the globe, among them: China, Middle Eastern and Mediterranean countries, South American countries, United States, various islands around the world (Angelakis, Marecos, Bontoux, & Asano, 1999; Bahri, 1999; Bonomo, Nurizzo, & Rolle, 1999; Faby, Brissaud, & Bontoux, 1999; Mills, Alabaster, Mara, Pearson, & Thitai, 1992; Salgot & Pascual, 1996; and others). This source is especially important in regions with limited water resources where increased urban water demand (which usually results from a combination of population growth and increasing standards of living) is met by reducing water supply for irrigation, causing economic (and cultural) stress in the rural sector.

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PH: S1366-7017(01)00003-4
2. Reclaimed wastewater as part of the water resources

2.1. Closing the water balance

Treated wastewater may be considered as a ‘new’ water resource, which can be added to the general water balance of a region. This ‘new’ source can substitute conventional water (potable water) used for irrigation or for other purposes that do not require water of drinking quality, while releasing some of the pressure on the conventional water resources. Israel is presently reusing more than 65% of the total municipal sewage production of the country, and it is planned to reach more than 90% reuse during the next decade (Table 1). Reclaimed wastewater helps to close a negative water balance in a country where all the conventional water resources are exploited to their maximum capacity.

2.2. Protecting water resources from pollution

In regions with abundant water resources, the negative effect of pollution may be reduced by dilution of pollutants into large water bodies, where long retention times enable the degradation of some pollutants. In regions, which suffer from water shortage, water resources are exploited to their maximum capacity (or beyond it). This results in small water bodies and short retention times, generally accompanied by deterioration of water quality by pollution. Wastewater reuse practice enhances the quality of conventional water resources by two means:

1. By reducing the demand pressure on the conventional resources, resulting in larger water bodies and longer retention times.
2. By driving out one of the main sources of pollution: municipal sewage.

3. Resources management: wastewater versus water

3.1. Similarities

Management of wastewater resources has several common aspects with that of conventional water resources:

<table>
<thead>
<tr>
<th>Water sources</th>
<th>1995</th>
<th>Water demand</th>
<th>1995</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater irrigation</td>
<td>700</td>
<td>Wastewater &amp; Brackish water irrigation</td>
<td>400</td>
<td>600</td>
</tr>
</tbody>
</table>
| Freshwater irrigation | 900   | Water supply and demand in Israel by sectorsa

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**Seasonal storage** — Sewage is produced throughout the year while irrigation in the Mediterranean region is performed only during the dry summer. Thus, seasonal wastewater storage is required, as seasonal storage of potable water is necessary. At present, there are more than 200 open reservoirs receiving wastewater and other marginal waters in Israel, having a total storage capacity of about 120 million cubic meters.

**Multi-annual storage** — Agricultural water demand varies from year to year. This is due to large differences between years in: total annual rainfall, distribution of rain events, and the intensity of each rain event. Thus, some multi-annual storage capacity can optimize the exploitation of the wastewater resource. The largest sewage treatment and reuse system in Israel — Greater Tel Aviv — (Kanarek & Michail, 1996; Icekson-Tal & Blanc, 1999) has an aquifer reservoir for both seasonal and multi-annual storage (Fig. 2).

**Scope** — Like schemes for conventional water resources utilization, wastewater reclamation projects may be local, regional or inter-regional. Table 2 lists some examples of wastewater reclamation projects of varying scopes in Israel. The inter-regional scheme of Haifa (Shelef & Azov, 1991; Tal, 1994) conveys treated effluents for 28 km from the Haifa Treatment Plant to the center of the Jezreel Valley where it is used for irrigation. The inter-regional scheme of Tel Aviv transports treated effluents for more than 100 km from the Tel Aviv Treatment Plant and SAT system to the Negev Desert, where agricultural development could hardly be performed without this ‘new’ source of water.

**Multiple sources** — Wastewater reclamation schemes may receive wastewater from a single source or from several ones, a mixture of treated wastewater and some marginal waters, or a mixture of reclaimed wastewater and conventional water. Multiple source schemes can optimize their inputs to obtain maximum quantity and quality of water for irrigation.

**Multiple uses** — Reclaimed wastewater can be reused more than once as part of an integrated water resources management. Reclaimed wastewater are designed to be discharged upstream in some rivers in Israel in order to recover dried and polluted rivers. The water will be then recaptured downstream for irrigation of parks along the banks of the river, for irrigation of agriculture crops, and various other uses (Fig. 1) (Friedler & Juanico, 1995, 1996a, 1997).

### 3.2. Differences

Wastewater resources management differs from conventional water resources management in several aspects, the most important of which are listed herewith:

#### 3.2.1. A constant and reliable supply

One of the main characteristics of this ‘new’ source of water is that it is very reliable. Not only that its ‘production’ is relatively constant during the year, but also it is almost constant between years (with a tendency to increase as time elapses). This is due to the fact that this source does not depend on rain but on the production of municipal sewage. The constant supply differs from the ‘winter only’ and yearly varying supply of rainwater. The reliability of this source of water for irrigation allows investments in intensive agriculture, which can be less supported by unreliable sources such as rains in semi-arid regions.
Table 2
Wastewater reclamation projects of varying scopes in Israel — some examples

<table>
<thead>
<tr>
<th>Region/locality</th>
<th>Capacity(^{a}) (10(^6) MCM/Yr)</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Getaot Kibbutz</td>
<td>~0.14</td>
<td>Local</td>
</tr>
<tr>
<td>Gedera Council</td>
<td>~1.5</td>
<td>Local</td>
</tr>
<tr>
<td>Jeezrael Valley</td>
<td>~8</td>
<td>Regional</td>
</tr>
<tr>
<td>Greater Haifa City</td>
<td>~25</td>
<td>Inter-regional</td>
</tr>
<tr>
<td>Greater Tel Aviv City</td>
<td>~130</td>
<td>Inter-regional</td>
</tr>
</tbody>
</table>

\(^{a}\)MCM — million cubic meters.

Fig. 1. Four historical stages in the integrated wastewater resources management.
3.2.2. Quality and treatment

While the quality of conventional water sources usually is suitable for agricultural usage without treatment, the quality of wastewater makes it unsuitable for utilization without proper treatment. In order to enable the use of reclaimed wastewater for agricultural irrigation, it has to comply with agrotechnic, environmental and sanitary quality requirements. These requirements do not always coincide, as in the case of nutrients, where from the environmental point of view the concentration in the effluents should be as low as possible, while from the agrotechnic point of view a certain level of nutrients is desirable since it obviates the need for addition of costly fertilizers.

- The agrotechnic requirements are low salt concentration (Weber, Juanico, & Avnimelech, 1996), and storage capacity in order to regulate between sewage production and demand of treated wastewater for irrigation (which occurs only in certain hours/days/seasons). When drip irrigation is practised, relatively low clogging potential is essential in order to prevent clogging of the irrigation system (Teltsch, Juanico, Azov, Ben-Harim, & Shelef, 1991; Juanico, Ravid, Azov, & Teltsch, 1995).
- The environmental protection requirements are basically low concentration of heavy metals and xenobiotic compounds, controlled level of nutrients and salts, and no malodors.
- The sanitary requirements mainly refer to the pathogens present in domestic sewage (viruses, bacteria and parasites). One of the main concerns related to wastewater reuse is the potential transmission of diseases. Long-term experience in numerous countries shows that wastewater irrigation with properly treated effluents does not endanger public health (Shuval, Adin, Fatal, & Ravitz, 1985).

It should be noted that illegal irrigation with raw sewage, poorly treated effluents, or water from heavily contaminated rivers and lakes, is a common practice in regions that suffer from water shortage. This practice certainly endangers public health. In many cases, the discharge of wastewater to water bodies implies unwanted and uncontrolled wastewater reuse downstream. Thus, controlled reuse of wastewater may improve public health (directly or indirectly) instead of endangering it.

3.2.2.1. What quality should be met. A discussion about what is ‘proper treatment’ for wastewater irrigation from the sanitary point of view exists between two different schools. The conflicting points of view are based on different concepts and methodologies. This disagreement has led to two different guidelines, namely: The Californian Guidelines (State of California, 1978) and the World Health Organization Guidelines (WHO, 1989; Blumenthal, Mara, Peasey, Ruiz-Palacios, & Stott, 2000). These two schools may represent not only different scientific/technical approaches, but also different political/economic interests. However, the lack of international agreement of administrators and scientists from the two schools has not been an obstacle for the increasing growth of the wastewater irrigation practice.

The degree of sewage treatment required for wastewater reuse is not necessarily better and more expensive than the degree required for the release of effluents into water bodies. On the contrary, in some cases it may be cheaper. Nevertheless, it is important to stress that the quality of wastewater required for wastewater irrigation is different from the quality required for the release of wastewater in water bodies (e.g., regarding nutrient removal). Sewage treatment technologies
used for wastewater reuse projects may be different from those used for ‘conventional’ sewage treatment.

3.2.2.2. Approaches for municipal sewage treatment. There are two main technological approaches for wastewater treatment, i.e.: the intensive treatment approach and the extensive treatment approach.

**Intensive sewage treatment systems** (such as activated sludge) are optimized for biological oxygen demand (BOD) removal. Sewage is introduced to a large biomass of heterotrophic microorganisms together with intensive supply of oxygen. This results in efficient BOD removal, performed in relatively short time (residence time of 8–14h) and confined space, which has an obvious financial benefit especially in densely populated urban areas (Table 3). The disadvantage of the short residence time is the lack of buffer capacity, making the system sensitive to transient quality and quantity interruptions and thus reducing its reliability. Moreover, intensive treatment systems fail to efficiently remove detergents, heavy metals, xenobiotics, and pathogens as well, nor do they have any significant storage capacity. As a result of the above shortcomings, intensive systems alone cannot achieve the requirements for agricultural irrigation and have to be followed by polishing treatment systems. This polishing treatment can be one of two basic types:

1. To add **advanced intensive treatment units** for further treatment of effluent. These may include disinfection unit (chlorination, ozonation, UV, etc.), coagulation–floculation unit, filtration or even membrane filtration, activated carbon treatment, etc. The main disadvantages of this approach are high investments and operational costs, high energy consumption, and the release of series of sludges, the treatment and disposal of which are also difficult and expensive.
2. To add **extensive treatment units** (such as wastewater stabilization reservoirs, constructed wetlands, etc.) for further treatment of effluent. By doing so, the extensive unit will not suffer

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Extensive</th>
<th>Intensive</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal of:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD–COD</td>
<td>+/++</td>
<td>++/+++</td>
<td>++/+++</td>
</tr>
<tr>
<td>Nutrients</td>
<td>+/++</td>
<td>++/+++</td>
<td>++/+++</td>
</tr>
<tr>
<td>Pathogens</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Hard detergents</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Refractory organics</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Salts</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sludge production</td>
<td>–/+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Land use</td>
<td>+++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Energy requirement</td>
<td>+</td>
<td>+/+++</td>
<td>+</td>
</tr>
<tr>
<td>Storage capacity</td>
<td>+/++</td>
<td>–</td>
<td>++/+++</td>
</tr>
<tr>
<td>Buffer capacity</td>
<td>+/++</td>
<td>–</td>
<td>++/+++</td>
</tr>
</tbody>
</table>

* (−) None, (+) low, (+++) medium, (+++) high.

Table 3

<table>
<thead>
<tr>
<th>Some characteristics of intensive and extensive treatment units a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Removal of:</td>
</tr>
<tr>
<td>BOD–COD</td>
</tr>
<tr>
<td>Nutrients</td>
</tr>
<tr>
<td>Pathogens</td>
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<tr>
<td>Heavy metals</td>
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<td>Salts</td>
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<tr>
<td>Storage capacity</td>
</tr>
<tr>
<td>Buffer capacity</td>
</tr>
</tbody>
</table>

* (−) None, (+) low, (+++) medium, (+++) high.
from overloading, since most of the BOD has been removed in the intensive unit. As a result of the long residence time of effluent within the extensive units (which is measured in weeks or months rather than hours in the intensive units), low rate reactions become relevant. These low rate processes are responsible for the removal of the remaining ‘hard’ pollutants from the effluent of the intensive units. Moreover, the long residence time in the extensive units enables them to act as a buffer zone for short-term breakdown of the intensive reactors.

**Extensive sewage treatment systems** (such as stabilization pond, stabilization reservoirs, constructed wetlands, etc.) have one main disadvantage namely: their large land requirements. However, in arid and semi-arid countries the storage capacity is needed anyway, in order to regulate between sewage ‘production’ which occurs throughout the year and effluent demand for irrigation which occurs only during the dry summer months.

To conclude, combining the two types of treatment units, especially in arid and semi-arid countries, would lead to better treatment and thus better quality of effluent to be utilized for agricultural irrigation (Table 3).

It should be noted however, that adding extensive units after intensive ones might not be the most cost-effective solution. A proper combination for achieving high effluent quality while keeping costs to a minimum may include semi-intensive reactors for partial BOD removal (such as low energy aerated lagoons) followed by extensive units for the removal of refractory pollutants and pathogens, and further removal of the remaining BOD. Another possibility is to combine an intensive unit, having only relatively short residence time (in order to obtain only partial removal of BOD), followed by an extensive unit. Under different conditions, a proper combination might include a combination of extensive units exclusively.

### 3.2.3. Simultaneous storage and treatment

The goal of storage of conventional water is to match supply and demand. The goal of storage of wastewater is twofold (Fig. 2):

- To match supply and demand.
- To perform additional treatment and to equalize wastewater quality.

When the storage units are designed and operated to maximize effluent quality, the long residence time enables the low-rate reactions to become relevant. These reactions are responsible for the removal of the ‘hard’ pollutants remaining in the effluent of the intensive treatment units.

Open wastewater reservoirs which are designed to optimize wastewater treatment can remove organic matter (BOD, COD) and detergents by one order of magnitude, heavy metals to minimal concentrations, and faecal coliforms by five orders of magnitude (Juanico & Shelef, 1991, 1994; Liran, Juanico, & Shelef, 1994; Juanico et al., 1995; Juanico, 1996; Friedler & Juanico, 1996b; Muszkat, 1999, Chap. 14). In the Haifa wastewater reclamation scheme, the reservoirs are operated in series in a continuous mode (Fig. 2), while in the Jezreel Valley scheme (Friedler, 1999) the reservoirs are operated as sequential batch reservoirs (SBR).

Groundwater storage by means of soil aquifer treatment (SAT) (which originated in Arizona) requires a sandy aquifer with specific characteristics which are not found everywhere, but when available, its removal performance is even better than the performance of the reservoirs.
3.2.4. Dual distribution lines

The differences in quality between water and wastewater induce the construction of separated distribution lines. The risk of accidental interconnection between the two distribution systems is higher in practice than it seems theoretically, and in fact this occurred in a few cases in Israel. Some regulations have been developed to avoid these interconnections. For example, inter-crossing is avoided already at the design step always if possible, and wastewater pipes are painted red while water pipes are painted blue.

4. Economic benefits of wastewater reuse

This section does not intend to outline a comprehensive analysis of the economic benefits of wastewater reuse, but to highlight few points some of which are usually overlooked in the economic analyses. Sewage treatment and disposal has been traditionally paid by the city that produces the sewage. Wastewater irrigation introduces a new economic component in the formula: the farmers who will benefit from the treated wastewater. The farmers may purchase the treated wastewater from the urban sector, or invest into the sewage treatment plant, or cover the operational and maintenance costs. There are several potential different schemes between the
urban and rural sectors. This means that total costs for sewage treatment are somehow shared by both sectors:

- For the *urban sector* this means a reduction of the costs of sewage treatment.
- For the *rural sector* this means an access to a reliable source of water for irrigation at a lower cost than the cost of importing conventional water from distant sources.

Three components are generally neglected in the cost/benefit analysis of sewage treatment and reuse projects:

1. One of the economic benefits of wastewater reuse in arid and semi-arid areas is the boosting of agriculture development that would not be possible without a constant and reliable supply of water. This component (agriculture development) is generally neglected in the cost–benefit since the analysis is generally limited to investment and operational costs on the one hand and potential revenues from selling the treated wastewater on the other.
2. Other issues, which are generally overlooked, are the resulting environmental and public health protection even if they are conspicuous, due to the difficulties to assign economic values to these parameters.
3. The cost–benefit analysis usually is performed for a 20 years period, while the lifetime of wastewater storage reservoirs and similar units is at least 40 years (and may be much more). Thus, the annual repayment for capital recovery is in practice lower than the one usually calculated.

5. Summary

Reuse of treated wastewater is a common and rapidly increasing practice, mainly in arid and semi-arid regions around the world. There, treated wastewater serves as a ‘new’ resource which is added to the water balance and substitutes conventional water in agricultural irrigation. Wastewater reuse may enhance the quality of conventional water resources by reducing demand pressure and by eliminating the main pollution source (municipal sewage) from the conventional water resources.

Management of water resources and wastewater resources has several common aspects, such as a need for seasonal and/or multi-annual storage, varying scope/size, multiple sources and multiple uses. Nevertheless, management of these two resources presents some differences:

- Wastewater supply is more reliable (does not depend on precipitation, but on production of municipal sewage).
- All wastewaters have to undergo proper treatment in order to comply with agrotechnic, environmental and sanitary requirements. This could be achieved either by intensive treatment systems or by extensive treatment systems, each having its own merits and deficiencies. Combining these two types of treatment may amplify the merit of each one, while minimizing their drawbacks.
- Storage of water is mainly performed for regulation between supply and demand, while storage of wastewater has an extra goal: to perform additional treatment and to equalize the quality.
- Utilization of wastewater necessitates construction of dual distribution lines.
Some economic benefits of wastewater reuse are

- The total costs of wastewater treatment can be shared between the urban and the rural sector. The urban sector will benefit from a reduction in treatment costs, while the rural sector will benefit from a reliable source of water at lower cost than conventional water imported from a distant source.
- Boosting of agriculture development that would not be possible without constant reliable water (wastewater) supply.
- Enhancement of environmental and public health protection which is conspicuous, but difficult to be assigned with economic values.

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