Evaluating water resources availability and wastewater reuse importance in the water resources management of small Mediterranean municipal districts

Thrasyvoulos Manios\textsuperscript{a,}\ast, Ioannis K. Tsanis\textsuperscript{b}

\textsuperscript{a} School of Agricultural Technology, Technological Education Institute of Crete, Heraklion 71004, Crete, Greece
\textsuperscript{b} Department of Environmental Engineering, Technical University of Crete, Chania 72000, Crete, Greece

Received 1 September 2005; received in revised form 7 November 2005; accepted 14 November 2005
Available online 20 December 2005

Abstract

Two low-cost and user-friendly models were developed in an effort to allow small Mediterranean municipalities to evaluate the water resources availability and wastewater reuse importance in their municipal districts. The Water Resources Balance Model (WRBM) ranks each municipal district in four categories according to an innovating scoring methodology based on the adequacy of the existing water resources for potable and irrigation needs. The Wastewater Reuse Importance Model (WRIM) was then used to evaluate the importance of wastewater reuse in water resources balance based on a scoring procedure in which the amount of reusable wastewater was compared with various scenarios of irrigation shortages and needs. The models were applied to 82 municipal districts from the prefecture of Heraklion in the island of Crete. WRBM evaluated eight districts as water scarce while 72% of the districts are water adequate. WRIM evaluated that in 67% of the districts, wastewater reuse is incapable of playing any role of any importance since either water is adequate or the shortage is so great and/or the produced wastewater volume is insignificant by comparison. In total, in only 11 of the districts could wastewater reuse be considered as an important alternative water resource.

\ast Corresponding author. Tel.: +30 2810 379400; fax: +30 2810 318204.
E-mail addresses: tmanios@steg.teiher.gr (T. Manios), tsanis@enveng.tuc.gr (I.K. Tsanis).
1. Introduction

The Region of Crete is one of the 13 regions of Greece, the geographical boundaries of which coincide with those of the homonymous island at the southernmost end of the country. They also coincide with one of the 14 hydrological compartments of Greece (Tsanis and Naoum, 2003). Political interests and disputes among the four prefectures and the more than 100 municipalities of the island, as well as poor water management, have created a public belief that water resources are inadequate and that some kind of drought is imminent. As a result many people often mention and believe that substantial and costly infrastructure is required to combat the problem. This infrastructure focuses more on increasing the amounts of available water than on reducing the water losses of the distribution network which in Heraklion, the capital of the island, is greater than 40% of the total amount of water pumped into the city. In a similar approach, wastewater reclamation and reuse has been considered as an important alternative solution to the water problems, especially for the irrigation of the dominant olive tree cultivations (Angelakis et al., 1999; Lazarova et al., 2001; Tanik et al., 2005).

Due to all this pressure, in 1999 the Region of Crete selected a consortium of Greek and European consulting companies to execute a survey concerning the island’s water resources. The study lasted two years and cost almost 700,000 euros. The funds were provided by the INTEREG II programme through the INTERISK action (RC, 2004). The results were presented to the public in Heraklion, in December 2002. One of the many condensed conclusions that can be drawn from the impressive and detailed work was the 65.9 and 90.2% water adequacy for irrigation and other uses (including domestic, industrial and animal irrigation), respectively, giving an average of 72.2% adequacy of fresh water resources. These percentages represent a picture of an island with some sufficiency in water resources which, however, cannot be considered dramatically scarce. In support of this statement, it must be mentioned that during the summer period more than 3,000,000 tourists visit the island (GNTO, 2004). In this survey, it was clearly stated for the first time that water cannot, at the moment at least, be considered as a restricting development parameter.

There was of course the argument that in the survey, the municipality was the smallest unit for which data were collected and water balances were evaluated. However, about 10 years before the survey, a major legislative change in Greece merged small communities with hitherto independent local authorities into far more viable municipalities. These communities had been created mainly by physical and geographical barriers and slow social processes over the past few hundred years. The new municipalities were an instant political creation often unifying communities (now renamed as municipal districts) with large differences in morphological, economical and environmental characteristics. In Crete, especially, a mountainous island with two peaks of height more than 2400 m, these physical divisions were and are still very strong. As a result, the INTERISK II survey could regard a municipality as a whole, and water resources as adequate or inadequate, whereas some of its districts were confronted with completely different circumstances. This is the case with most water resources balance models, which in most cases focus on areas larger than 1000 km² (Bronstert et al., 2000; Mitchell et al., 2001).
Additionally, it is characteristic of the southern Mediterranean area, in the centre of which Crete is situated, that water consumption increases dramatically between May and September of each year. It is during this period that both tourism and agriculture present their highest needs for water, often competing for the same source. The amount of rainfall during that period is very little and incapable of playing any direct and important role. As a result, water balances for these areas should be mainly focused on the dry summer period.

The aim of this research effort was to develop two simplified, low-cost models which will allow (a) the evaluation of the water resources availability of a small municipality or any municipal districts in the Mediterranean region, and (b) the evaluation of the importance of wastewater reuse in the water resources management in the same areas. The models use simple and common spreadsheet EXCEL and a variety of data that are easily collected in a municipality. The combination of low-cost software and easily collectable data will allow the scientific personnel of a municipality to evaluate both parameters with adequacy and at minimum cost.

2. Method: model development

For the development of the models, information and ideas presented by Bronstert et al. (2000), Croke et al. (2000), Mitchell et al. (2001) and Al-Jamal et al. (2002) were used.

2.1. The Water Resources Balance Model

Fig. 1 provides a general schematic presentation of the model used to estimate the water resources balance in each district and providing the base for developing the respective model, called the Water Resources Balance Model or WRBM in short. As seen in Fig. 1, the water which flows into a district comes from rain, natural springs, rivers and drillings as well as reservoirs, dams and occasionally from other municipal districts. The water consumed in a district is used by industry, agriculture (including animal farming) and households or it flows towards another district.

As mentioned in Section 1, the period of high water demand in Crete is between May and September due to tourism and the irrigation of olive and citrus trees, vineyards and vegetables in greenhouses as well as in open fields (GNTO, 2004; Maliarakis, 1999). Therefore, the WRBM was developed for this specific period, taking into consideration water consumption and supply for a period of five months: May, June, July, August and September.

As a result and since rain has no direct role in covering the water needs of this period, especially for irrigation purposes, it is not included in the model. The indirect role that rain has in water availability through the recharging of underground water resources, supplying both springs and drillings as well as filling dams and reservoirs, is not specifically evaluated for simplicity reasons. Efforts were made to include the rain parameter through the water supply from springs and drillings by using the average value of the longest possible period when such data were available. The absence of rivers in Fig. 1 is due to the lack of permanent rivers in Crete. Most river basins operate as drains for forwarding either rainwater or snowmelt into the sea and are dry by the middle of May to the first rainfall. There is only a single case of one such seasonal river, which feeds the largest dam (16,000,000 m$^3$) on
the island, in the prefecture of Lassithi. As far as dams and reservoirs are concerned, at the moment all store water for agricultural use alone. In the interests of simplicity, these dams will be considered at full capacity in the beginning of May.

The optimum amount of water per 1000 m² of vines, olive trees, greenhouse vegetables, open fields vegetables and grain cultivations during the five-month summer period in Crete is 300, 250, 650, 500 and 700 m³, respectively. For every individual permanent resident of each community, daily water consumption was regarded as 220 L, while for each tourist that amount was double, reaching 440 L. These amounts include losses in the distribution system. Industrial consumption varies according to the size and product of the unit whereas animal consumption varies between 20 L per day for a mule and 100 L per day for a cow. Finally, data of water flow towards a neighbouring municipal district were calculated based on averages of the longest period available.

In order to develop the WRBM, the following data were collected from 82 municipal districts in 15 different municipalities in the prefecture of Heraklion. Data were collected from various Ministries, the Region of Crete, the National Statistical Service and local authorities concerning population size in each district, land distribution of various cultivations and their
water needs during the summer period, number and kind of animals, industries, etc. Data were also collected on the water resources of each district such as springs, drills, reservoirs and dams. Specifically, the following were taken into consideration:

(i) population in total and individual communities of each municipal district as recorded by the 2001 national population register of the National Statistical Services (NSS, 2004),
(ii) number of animals including the domestic and farm animals as detailed in the Ministry of Agriculture database (MA, 2004) and NSS data (NSS, 2004),
(iii) land coverage of various cultivations based on information from the MA (MA, 2004) and local authorities (LA),
(iv) land coverage of irrigated cultivations based on information from the MA (MA, 2004) and LA,
(v) local industries and their monthly water consumption, through the NSS, the Ministry of Development (MD, 2004) and LA,
(vi) number of rooms available in hotels, through the National Tourism Organization (GNTO, 2005) and LA,
(vii) natural springs or drillings for fresh water and their average hourly flow from the Region of Crete (RC, 2004) and LA,
(viii) local water reservoirs including their capacities from the RC and LA, and
(ix) flow of water from and to neighbouring districts mainly from Local Municipal Water Authorities (LMWA).

Based on this information, the following were estimated on a monthly basis:

(a) the amount of water consumed by people (local and tourists), animals and local industries based on relevant information collected from various sources,
(b) the optimum amount needed for the existing irrigated land as well as the required amounts for irrigating 50 and 75% of the cultivated land, based on the per 1000 m² cultivation optimum requirements,
(c) the total amount of water required for the industries,
(d) the total amount flowing in and out between the municipal district and a neighbouring one.

Fig. 1 represents schematically the calculating process through which the adequacy of fresh water is calculated in the WRBM. The total amount of water flowing into the municipal district is divided into two groups based on quality: quality A which can be used by humans, animals and industries, and quality B which can be used for irrigation. From the monthly incoming of quality A, the amount required for each month for human consumption is subtracted, followed by the amount used for animal irrigation and then that used in industries. If the amount of water needed for all three uses is greater than the quality A inflow, then the amount needed for industrial uses is shifted to quality B. If the total is still negative, then animal watering is also shifted into quality group B.

The remaining monthly quantity of quality A water, after the above deductions, is used for irrigation. To this amount is added the amount of quality B water that can be used for irrigation on a monthly basis. The amount of available water in dams and reservoirs is divided by five and the total is added to the available quality B water for each month.
The result of the entire process is a number representing the amount of water available for irrigation in each of the five months.

This amount is compared to the amount of water required in cubic metres for covering completely the irrigation needs of the existing irrigated land, the amount needed for the irrigation of 50% of the cultivated land and that needed for the irrigation of 75% of the cultivated land. These comparisons are given in the form of percentages. At this point the WRBM has calculated three percentages (Fig. 2). These percentages are corresponded into points through the scoring presented in Table 1. Table 2 represents how the various scores of Table 1 were combined to provide the four different water resources balance groups in which each municipal district would be placed. Eq. (1) represents how the final score is calculated:

\[
\text{WRBM}_{\text{score}} = (\text{EIL} + I_{50} + I_{75})CF_1
\]

where EIL: existing irrigated land; I_{50}: irrigating 50% of cultivations; I_{75}: irrigating 75% of cultivations; WUP: water use parameter (Eq. (2)).

\[
\text{WUP} = \frac{\text{total amount of water used by humans, animals and industry}}{\text{amount of quality A water consumed}}
\]
Table 1
Corresponding percentages of covering irrigation needs to points

<table>
<thead>
<tr>
<th>Existing irrigated land</th>
<th>Irrigating 50% of cultivations</th>
<th>Irrigating 75% of cultivations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>Points</td>
<td>Percentage</td>
</tr>
<tr>
<td>&lt;5</td>
<td>12</td>
<td>&lt;5</td>
</tr>
<tr>
<td>5–10</td>
<td>11</td>
<td>10–20</td>
</tr>
<tr>
<td>10–15</td>
<td>10</td>
<td>20–30</td>
</tr>
<tr>
<td>15–20</td>
<td>9</td>
<td>30–40</td>
</tr>
<tr>
<td>20–25</td>
<td>8</td>
<td>40–50</td>
</tr>
<tr>
<td>25–30</td>
<td>7</td>
<td>50–60</td>
</tr>
<tr>
<td>30–35</td>
<td>6</td>
<td>60–100</td>
</tr>
<tr>
<td>35–40</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>40–50</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>50–60</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>60–70</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>70–80</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>80–100</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

This parameter WUP can take values only between 1 and 2. If the above fraction produces numbers greater than 2 or smaller than 1, then these numbers are replaced by 2 and 1, respectively. These limits were set in order to control the effect of the WUP in the scoring process allowing the final score to be near the limits of each category as follows. Through the WUP, the WRBM can be adjusted in order to elaborate the potential inadequacy of quality A water. Since that quality of water is used for human consumption, any potential inadequacy represents an important problem. When the score recorded for a municipal district is multiplied by a WUP greater than 1, then the new final score may result in the group moving towards a more water scarce situation. This is demonstrated by the short characterisation given in the four groups representing a respective number of water resource balances:

- Group A (0–6): water resources balance is positive and water is adequate for at least the coming decade.
- Group B (7–11): water resources balance is positive but at a critical point and development in the coming decade might create some water scarcity.

Table 2
Grouping of the various scores used by WRBM

<table>
<thead>
<tr>
<th>Category</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covering the optimum needs of the existing irrigated cultivations</td>
<td>0–3</td>
<td>4–6</td>
<td>7–9</td>
<td>9–12</td>
</tr>
<tr>
<td>Covering the optimum needs of 50% of the cultivations</td>
<td>0–2</td>
<td>2–3</td>
<td>3–5</td>
<td>5–6</td>
</tr>
<tr>
<td>Covering the optimum needs of 75% of the cultivations</td>
<td>0–1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>0–6</td>
<td>7–11</td>
<td>12–16</td>
<td>17–21</td>
</tr>
</tbody>
</table>
• Group C (12–16): water resources balance is negative and the development of alternative resources is required, including the possibility of transporting water from neighbouring areas.
• Group D (17–21): water resources balance is extremely negative, water is scarce and an immediate, reasonable-cost solution is needed.

2.2. The Wastewater Reuse Importance Model (WRIM)

The WRIM was developed, as mentioned in Section 1, in order to evaluate the importance of wastewater reuse in the water resource management of a small municipality or municipal district. Again for reasons of simplicity, the total and the maximum number of people (locals and tourists) residing in a district were used to estimate the amount of wastewater produced in that district. For each local person this amount was regarded as 150 L per day, while for each tourist this amount was doubled to 300 L per day as suggested by Tchobanoglous and Burton (1991). When the total amount was estimated, it was used in the WRIM to evaluate the following four parameters:

i. the ability of the produced and reclaimed wastewater to cover the water shortage of irrigating completely the existing irrigated cultivations (Table 3),
ii. the ability of the produced and reclaimed wastewater to cover the water shortage of irrigating completely 50% of the cultivations (Table 3),
iii. the ability of the produced and reclaimed wastewater to cover the water shortage of irrigating completely 75% of the cultivations (Table 3),

Table 3
Corresponding percentages of converting irrigation shortage to points

<table>
<thead>
<tr>
<th>Percentage of existing irrigated land</th>
<th>Points</th>
<th>Percentage of irrigating 50% of cultivations</th>
<th>Points</th>
<th>Percentage of irrigating 75% of cultivations</th>
<th>Points</th>
<th>Percentage of olive tree irrigation</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5</td>
<td>10</td>
<td>0–5</td>
<td>12</td>
<td>0–5</td>
<td>14</td>
<td>20–40</td>
<td>3</td>
</tr>
<tr>
<td>5–10</td>
<td>9</td>
<td>5–10</td>
<td>11</td>
<td>5–10</td>
<td>13</td>
<td>40–60</td>
<td>2</td>
</tr>
<tr>
<td>10–20</td>
<td>8</td>
<td>10–15</td>
<td>10</td>
<td>10–15</td>
<td>12</td>
<td>&gt;60</td>
<td>1</td>
</tr>
<tr>
<td>20–30</td>
<td>7</td>
<td>15–20</td>
<td>9</td>
<td>15–20</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30–40</td>
<td>6</td>
<td>20–25</td>
<td>8</td>
<td>20–25</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40–50</td>
<td>5</td>
<td>25–30</td>
<td>7</td>
<td>25–30</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50–60</td>
<td>4</td>
<td>30–40</td>
<td>6</td>
<td>30–40</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60–70</td>
<td>3</td>
<td>40–50</td>
<td>5</td>
<td>40–50</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70–80</td>
<td>2</td>
<td>50–60</td>
<td>4</td>
<td>50–60</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80–90</td>
<td>1</td>
<td>60–70</td>
<td>3</td>
<td>45–50</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90–100</td>
<td>0</td>
<td>70–80</td>
<td>2</td>
<td>50–60</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60–70</td>
<td>3</td>
<td>40–50</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>70–80</td>
<td>2</td>
<td>50–60</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>80–90</td>
<td>1</td>
<td>40–50</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>90–100</td>
<td>0</td>
<td>50–60</td>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* There is no shortage of fresh water.
iv. the ability of the produced and reclaimed wastewater to cover the irrigation needs of 10% of olive tree cultivations (Table 3).

The first three parameters indirectly include the water resources balance evaluation since adequacy or shortage of water resources to cover irrigation needs results in a corresponding need for smaller or greater amounts of wastewater to do so. However, another parameter directly related to the results of the WRBM is used at the end of the calculations. Water reuse parameter (WRP) is also applied after the end of the calculation and is far simpler than WUP. It allows the user to add one of three numbers (−1, 0 and 1) to the score regarding the original placement of the municipal district in the WRBM. For municipal districts in group A, the number −1 is added to their score, for groups B and C the number 0, and for group D the number 1. There were two reasons for which WRP was incorporated into the WRIM: (a) it was an effort to increase the direct effect of water resources adequacy into the calculating model and (b) to allow some differentiation among the group since as presented in Table 4, all of them have common boundaries with both the previous and the next group. For example, for a group A district the scoring prior to the WRP was 19, then the district should be placed either in category I or II. Through the WRP the addition of value −1 results in placing the district in group I. If the results are placing the same district in group II, for example, with a score of 20 and the WRP is changing that into 19, then the district is still placed in group II. Eq. (3) represents the way the final score for the WRIM is calculated:

$$\text{WRIM score} = \text{SEIL} + \text{CSI}_{50} + \text{CSI}_{75} + \text{COT}_{10} + \text{WRP}$$  \tag{3}$$

where CSEIL: covering the shortage of existing irrigated land; CSI_{50}: covering the shortage of irrigating 50% of cultivations; CSI_{75}: covering the shortage of irrigating 75% of cultivations; COT_{10}: covering 10% of olive tree irrigation; WRP: water reuse parameter.

The various scores were combined as presented in Table 4, also producing four different categories of wastewater reuse importance (Table 4):

- Group I (1–19): water resources are adequate and wastewater reuse is not really necessary since it will have no important role to play in water resources management.
- Group II (19–27): wastewater reuse might have an important role to play in water resources management since the amounts required to cover irrigation needs are such and the volume of wastewater produced in the district is enough to cover them to a significant degree.

<table>
<thead>
<tr>
<th>Category</th>
<th>Group I</th>
<th>Group II</th>
<th>Group III</th>
<th>Group IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covering the shortage of existing irrigated cultivations</td>
<td>0–4</td>
<td>5–6</td>
<td>7–8</td>
<td>9–10</td>
</tr>
<tr>
<td>Covering the shortage of 50% of the cultivations</td>
<td>0–5</td>
<td>6–8</td>
<td>9–10</td>
<td>11–12</td>
</tr>
<tr>
<td>Covering the shortage of 75% of the cultivations</td>
<td>0–6</td>
<td>7–9</td>
<td>10–12</td>
<td>13–14</td>
</tr>
<tr>
<td>Irrigation of 10% of olive trees</td>
<td>1–4</td>
<td>1–4</td>
<td>1–4</td>
<td>1–4</td>
</tr>
<tr>
<td>Total</td>
<td>1–19</td>
<td>19–27</td>
<td>27–34</td>
<td>34–40</td>
</tr>
</tbody>
</table>
• Group III (27–34): wastewater reuse can have a small role to play in water resources management since the volume of wastewater produced in the district cannot cover the district’s water needs to a significant degree.

• Group IV (34–40): wastewater reuse cannot play any important role in water resources management since the amount required for covering irrigation needs is very large and/or the amount of wastewater produced is very small.

3. Results and discussion

In total, data from 82 districts in 15 municipalities in the prefecture of Heraklion in the centre of the island were used to evaluate the two models presented above. The original intention was to evaluate all the districts (over 150) in all 27 municipalities of the prefecture. However, that was impossible to achieve, mainly due to lack of data for all the districts for various reasons:

• No data were available from the municipalities due to a breakdown in communication between municipal and central government authorities. This conflict was very pronounced in some municipalities although in the great majority of cases collaboration was smooth and information sharing continuous.

• No data were provided by the municipalities or the Municipal Water Authorities. In a small number of authorities, the personnel (public servants) confronted this research with disbelief. Excuses were often found either to delay the information flow or to completely conceal data. In some cases and under severe pressure from their elected political heads, data were finally provided.

• No data were available in the various Ministries. It was often the case that data did not exist for all the districts in some of the ministries involved. However, it must be mentioned that all requested and available information was provided with no problem and at very short notice.

• No data were available from the NSS. This was the less severe problem. Either the NSS had not managed to process all the information from the 2001 inventory or the creation of new districts in the municipalities resulted in lack of information.

The data collection process was rather difficult and time-consuming since more than one visit to each municipality was often required in order to collect all the necessary information. In the majority of municipalities this effort was viewed with interest and people took great pleasure in sharing information about their area. It was often necessary to talk directly to districts representatives, who cooperated better than anyone. More than six months’ work was needed to collect all the data for Heraklion prefecture, a small fraction of which were used in this paper and only for those districts with complete set of information.

Fig. 3 represents the distribution of these districts in WRBM groups A, B, C and D. The derived results are rather optimistic for the water resources balance in the prefecture of Heraklion. The majority of districts (51.2%) scored enough points to be in group A, which describes districts with adequate fresh water resources for at least the next decade. If the districts in group B (barely adequate water resources) are added, then the percentage of districts with some water adequacy was above 72.0%. As mentioned in Section 1, the
INTERISK survey suggested that 65.9% of irrigation and 90.2% of all other uses are adequately balanced by the existing water resources, giving an average of 72.2%. According to Tsakis and Naoum (2003), the average estimated water requirement for irrigation for the whole island is similar to those in Heraklion prefecture.

According to Croke et al. (2000), who studied the Messara valley in the South of the Heraklion prefecture, during 1985 and 1995 there was an annual net loss from catchment ground water store of 46 mm. Over-pumping was (and remains) the main reason for that. The ground water level has dropped approximately 20 m over the past 10 years according to the authors. These findings indicate the fact that in an effort to cover the increasing water demands local farmers turn to groundwater reservoirs. Over-pumping, no matter how dangerous it could be for the water resources, is the practice that retains the available water in the required levels. These results support the accuracy of WRBM analyses.

However, 28.0% of the districts in groups C and D cannot be considered small or insignificant. For example, the municipal district of Ano Archanes, in the Municipality of Archanes, one of the most historical and fast growing districts in the island, is placed in group C, with 15 points together with another 15 districts. Seven other districts were placed in group D which means that they are dealing with substantial water problems. It is in these districts that lack of water can be considered as a barrier to development in the near future.

The most characteristic example is that of the municipal district of Achlada in the Municipality of Gazi which scored 21 points, the maximum possible score without the activation of WUP. It is a well-developed tourist area with an extremely mountainous terrain and a considerable need for irrigation water. In this district water quality A is barely enough and 80% is used for human consumption. The municipality is known to be looking at all possible ways of dealing with the water scarcity problem. At the moment, water tankers are very often used to transfer water.

The fact that in no case was the WUP parameter activated, even in the Achlada district, should be considered a positive result for the water balance analyses of the area. This should be expected since covering the needs for quality A is the main priority for any local authority in the island as well as the central government. Plans for developing larger hotels (resorts), golf courses in Heraklion and a new international airport in the centre of the prefecture could...
put some additional pressure on water resources, especially in groups C and D districts, resulting in a lack of adequate quality A water for industry and animal farming.

It is also mentioned in Section 1 that wastewater reclamation and reuse is often presented as an alternative low-cost, viable solution for scarce water resources which can help minimise the problem by replacing fresh water, especially for olive tree irrigation. WRIM was used to estimate how important that practice could be for the 82 districts and Fig. 4 presents the results of this analysis.

The majority of districts (44 of the 82) achieved scores that introduce them to group IV, meaning that either the required amount of water was so large and/or the produced wastewater was so small that wastewater reuse would have no effect on the overall water balance. Each hectare of olive trees requires approximately 2500 m$^3$ for the five-month irrigation season or an average of 16.5 m$^3$ per day. This amount is produced as wastewater by 110 people. However, in most municipal districts of the island the total population (often found dispersed in more than one village) very rarely exceeds 2000, even during the summer, supplying adequate water for no more than 20 ha—an extremely small amount of cultivated land. In the districts analysed, olive tree cultivation covered 5013 ha. For that land to be sufficiently irrigated with wastewater would require a city of over 55,000 inhabitants. RC (2004) has estimated the cultivated land in the prefecture of Heraklion at 12,117 ha. This approach on the significance of wastewater reuse was also supported by Vazquez Montiel et al. (1996) and Mitchell et al. (2003).

Group I represents those districts in which the reuse of wastewater is not necessary due to adequate water resources. There are 11 such districts out of the 82. All group I districts also belong to WRBM group A, a fact which indicates the accuracy of both models. In group IV, distribution is more uniform among the WRBM groups, suggesting that the inadequacy of wastewater reuse lies with the fact that the population is too small to produce significant volumes. By combining groups I and IV it was found that in 67.1% of the districts analysed, wastewater reuse cannot play a role of any importance because it would not provide any significant help.

Ten districts are recorded in group II, where wastewater reuse could have some role to play in water resources management (Fig. 4). The fact that in this group there is a district from group D of the WRBM is significant (Fig. 5). This district is that of Achlada, which as mentioned earlier is a developed tourist resort with the equivalent of over 11,000 people.

---

![Fig. 4. Distribution of the municipal districts in the various water resources balance groups of WRIM.](image-url)
producing more than 1650 m³ per day, able to irrigate 100 ha of olive trees, where only 30 ha are recorded in the district. Under such circumstances, wastewater reuse should have an important role to play in water resources balance and appropriate planning should be initiated. The presence of four group B and three group C districts in the third WRIM category is required since such groups present the water shortage that wastewater reuse might be able to remedy. The fact that they are registered in group III indicates that the ratio between water needed and wastewater produced barely allows them to play a role.

The presence of six districts from group A in group II is explained by the low shortage of the existing water resources for irrigation in these districts, which allows the wastewater volume produced to have some comparable value (Fig. 5). A similar explanation is given for the 10 group A districts found in group III (Fig. 5). These 16 group A districts found in groups II and III should be considered as districts in which wastewater reuse could have some role but it is not required, at least by present standards. If these districts are added to the ones found in groups I and IV, then the total percentage of districts in which wastewater reuse is either not necessary or would have no effect whatever is 86.6%.

4. Conclusions

In total, 82 municipal districts were analysed from 15 different municipalities in the prefecture of Heraklion, one of the most water scarce prefectures in Greece, using two models. The conclusions of this analysis are the following:

- The lack of abundant fresh water resources in the island is indisputable with the level of adequacy still not accurately determined. In this work, however, 72.0% of the districts studied presented some water adequacy.
- Wastewater reclamation and reuse could not play an important role in the balance of water resources mainly because the major towns and cities are at a considerable distance from the areas where water for irrigation is mostly needed. Only areas with more than 10,000 inhabitants (permanent or not) could provide an adequate amount of wastewater which would make an important difference.
The reuse of wastewater produced from such large cities such as Heraklion with a population of more than 200,000 in such areas would definitely result in a revolution in water resources balance, which however must be evaluated both technically and financially.

Another restrictive parameter of direct wastewater reuse is the fact that it is only needed during the summer period. As a result, substantial amount of water produced in the winter is lost. Wastewater reservoirs and underground water charging should also be studied and evaluated.

At present, wastewater reuse design and implementation should be considered as an alternative tool for extreme water shortage phenomena (e.g., a drought) and not as a permanent additional water resource.

Acknowledgements

We would like to thank Mr D. Papamastorakis and Mr M. Kritsotakis from the Directorate of Planning and Development, Department of Water Resources Management of the Region of Crete for their help and cooperation and also the students of Technological Education Institute of Crete, G. Adamopoulos and X. Oikonomou for their help in data collection. Dr Manios was funded for this work by the Greek National Scholarships Institute.

References


Maliarakis M. Cultivations irrigation: Report for the Municipality of Therapans, Heraklion, Crete. Laboratory of Natural Resources and Environment, National Agricultural Research Institute of Greece; 1999.


