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Current status in wastewater treatment, reuse and research in some mediterranean countries

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ABSTRACT

The status of treated wastewater reuse as experienced in some Mediterranean Basin countries such as Greece, Israel, Italy and Cyprus is examined. General background information is given for each of these Mediterranean countries, including natural water resources, climatic conditions (temperature, rainfall), generated wastewater, crops cultivated and irrigated with effluent, and related aspects of reuse. The examined parameters include treatment strategies, wastewater reuse standards applied in each country, effluent reuse research in progress in the above target countries related to the treatment technologies, water quality, regulations, economics, public acceptance, risk assessment, benefits, keys for potential success and main constraints. Emphasis has been given to the benefits of treated wastewater reuse in integrated water resources management systems and its role for water cycle management, solving water scarcity issues mainly in arid and semi-arid regions of the Mediterranean basin. The experience presented can be implemented in other water scarce regions around the world.

Keywords: Wastewater; Reuse; Mediterranean basin; Water scarce region; Irrigation; Agriculture

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1. Introduction

1.1. Scope of wastewater reuse in some Mediterranean countries

Population growth, elevated living standards, excessive exploitations of groundwater and climate changes, stress on clean water availability and supply the need to find alternative water sources. Environmental and health issues recall for further and improved treatment of so-called low-quality waters. The sectors of application and the typology of drivers for the development of Treated Waste Water Reclamation (TWWR) strategies in the Mediterranean include:

- (i) water resources and demand,
- (ii) wastewater aspects,
- (iii) irrigated agriculture fields,
- (iv) landscape and development of recreational and green areas,
- (v) health conditions, infections, diseases, epidemics diseases, and
- (vi) socio-economic aspects [1].

Municipal and industrial wastewaters can be treated and reused for diverse purposes, primarily for agricultural irrigation, recharge of aquifers and green areas. However, these wastewaters must be treated prior to utilization in order to prevent environmental pollution along with mitigation of health risks. Environmental pollution includes groundwater, agricultural fields, resort and reserve sites, beaches and seawater to which wastes of all kinds (even treated) are frequently disposed. Common municipal wastewater treatment can remove large fractions of organic matter, suspended solids, nutrients (nitrogen and phosphorus species) and trace contaminants (organic and inorganic) [2]. However, under common treatment conditions (waste stabilization ponds; activated sludge; trickling filters; rotating biological contactors), part of the pathogenic organisms still remain in the effluent, depending on effluent disinfection practices [3]. Dissolved solids and micro-pollutants are removed only to a limited level, unless special measures such as membrane treatment methods are employed. More recently, identified chemicals associated with human and animal pharmaceuticals and hormones are also identified at trace levels in municipal effluents [4–6] and livestock-based reuse streams [7]. Thus, while reuse is a desirable act from the water resource perspective, primarily in arid regions, its application for irrigation clearly requires adequate management phases of risk assessment. In the Mediterranean Basin, the predominant use of TWWR is agricultural irrigation, and it is quickly expanding. It is due to the fact that the agriculture sector withdrew a significant share of conventional water resources (an average of 65% in most Mediterranean countries considered, and over 80% in southern and eastern Mediterranean countries) [1,8,9].

The main risks that are associated with reclaimed wastewater reuse for irrigation stem from the followings: (i) food contamination and human infection by pathogens (bacteria, viruses, protozoa, helminthes); (ii) soil salinization and accumulation of various unknown constituents that might adversely affect agricultural production; and (iii) groundwater quality degradation by the various reclaimed water contaminants, migrating and accumulating in the soil and aquifers. Oron [10] showed that high virus levels in the applied effluent implementing Subsurface Drip Irrigation (SDI) system resulted in almost no penetration into the roots of tomato plants and no virus detected in the leaves and the fruits. However, the risk of consuming uncooked vegetables has prompted some situations that prohibit the use of reclaimed water for food crop irrigation, while others allow it only if the crop is to be processed prior to being available for consumption [11]. Hajjami and other colleagues evaluated recently the potential risk that humans and animals are exposed to, when wastewaters (raw and treated) are reused for irrigation [12]. It is based on studies with helminthes eggs which were conducted in Morocco [12]. The risk of applying effluent of different quality of treatment was as well studied by van Ginneken and Oron [13], indicating the advantages of SDI.

Different routes of contamination penetration are available during the harvest of leafy green vegetables. Harvest is a key step along the contamination pathway as it involves the injury of plant tissues. Injured surface are ideal sites for pathogen attachment and penetration into the plants and may also serve as an entryway of pathogens into the deeper tissues of the plant. These parts of the plants commonly cannot be disinfected or washed away [14,15]. Commonly, strict reuse criteria are imposed for unrestricted effluent reuses. High-quality effluent for unlimited reuse can be mainly obtained by membrane technology [16]. From an agronomic perspective, salinity and over-dosage of nutrients is a problem associated with irrigation in arid and semi-arid environments. Salinity conveyed by the irrigation water tends to accumulate in the soil, and can necessitate transitioning to more salt-tolerant crops [17–19].

Managing water scarcity is a global challenge that impacts food production; the environmental, social, economic and political cornerstones of humans' existence on earth. Effluent reclamation and reuse provides opportunities to efficiently utilize water and maintain the quality of the existing fresh water sources. Effluent reclamation is meant to help in closing the anthropogenic water cycle and enabling sustainable reuse of available water resources. When integrated water resources management is considered, it can be viewed as an integral part of environmental control and water management strategies. It may also result in benefits to public health, the environmentand economic development.

1.2. The purpose of the work

The main objective of this paper is to illustrate the benefits of treated wastewater reclamation in integrated water resources management systems and its role for water cycle management in some countries in the Mediterranean Basin. It will allow solving water scarcity issues, mainly in arid and semi-arid regions, adaptation to the new situations due to climate change and water in the mega-cities of the future. The paper will cover various aspects related to water reuse in the Mediterranean Basin, including treatment technologies, water quality, regulations, economics, public acceptance, risk assessment, benefits, main constraints and key issues for potential success. The analysis is based on relevant studies and reports, and a descriptive analysis of experiences from selected Mediterranean countries. The paper provides an informative background of each country of the study (location, population, climate, water resources, wastewater treatment and reuse, as well as wastewater reuse standards) which include Greece, Israel, Italy and Cyprus. Research on wastewater treatment by means of natural systems (waste stabilization ponds), accumulation of heavy metals in forest species and food plants, and assessment of the heavy metal pollution of soils is discussed for Greece. The risk assessment approach for safe effluent application, exposure characteristics combined with dose-response reaction and the use of nanotechnology for dissolved constituents' removal from secondary effluent is described for Israel. The advanced technologies for wastewater reclamation and reuse are presented for Italy. Research on the removal of urban wastewater organic xenobiotics is recorded for Cyprus.

2. Informative background referring to each country

2.1. Greece

Total mean annual rainfall in Greece (precipitation) is around 116,330 hm^3 per year. Total annual water consumption is given in Table 1. Undoubtedly, total available water potential could meet all requirements. Yet, during certain periods of drought, some parts of the country, mainly some islands and coastal zones, may experience serious shortage of natural water [20,21].

Some constraints prevent the full exploitation of all available waters and the related problems could be summarized as follows:

- Research which refers to the detailed definition of the hydrological parameters is spasmodic and uncoordinated on a national level.
- Problems related to the availability of water resources are steadily increasing due to concurrent increase of consumption, the decrease of inflowing waters from neighboring countries, irrational water use and over exploitation of the easily approachable water resources.
- Some regions of the country, mainly the islands and coastal areas, are facing water shortage problems.
- Irrigation water demands of crops are characterized by high costs for supply, storage and distribution. The lack of an efficient and equitable water pricing system is an additional handicap in the process of managing water allocation. Under the current status, private users of irrigation water bear their own capital and operational costs, which can be high (up to a maximum of 0.25–0.40 € per m^3). On the other hand, users of public collective projects pay a usually low water fee (i.e. a flat rate per hectare of irrigated land) to cover the administrative as well as the maintenance and operational costs of the projects. In average, this fee ranges from 120 to 500 € per ha, which is roughly equivalent to 0.02–0.08 € per m^3 [22].
- The progress that has been achieved in the improvement of wastewater treatment has increased to a great extent; however, surface waters became more polluted along with eutrophication processes. In Greece, the use of treated

Table 1
Annual water consumption/requirements in Greece [66]

Distribution of water consumption	Consumption hm^3/year	Percent
Irrigation	6,833	83
Animal husbandry	105	1.3
Industry	158	2.2
Public use (potable)	1,045	13
Other uses	100	1.2
Total	8,241	100.00

wastewater has been regulated and authorized for agricultural irrigation, landscape irrigation/golf courses, aquifer recharge, environment, industrial recycling, urban use and domestic use [1].

The quality of water in Greece does not generally pose special problems, except in isolated areas, mainly along the coastal zones. On a national level, the rational water use may save significant quantities of water that could be used for other purposes. Thus, around 5% reduction of the annual needs for irrigation water might save 4.2% of the total water consumption used on a national level, while 5% reduction in potable water would correspond to only 0.7% of the total national water demand.

There are close to 250 urban Wastewater Treatment Plants' (WWTPs), most of which are located in tourist regions. Fifty per cent of the total population is served by sewage systems, and towards the end of 2012 this was expected to increase to 65%. Around 1% of the wastewater is subjected to primary treatment, 83% to secondary treatment and 16% to advanced treatment. Eighty per cent of the WWTPs are based on activated sludge systems. So far, treated wastewater is reused only to a limited scale, and most of it is disposed into surface water bodies.

Interestingly, 83% of water consumption in Greece goes directly to irrigation (Table 1), while only 1% of the wastewater produced is actually reused for irrigation. A significantly high percentage (99%) of the rest is disposed in the environment.

2.2. Israel

Water supply is based on central systems controlled by Mekorot (national water supply company). Rain varies from about 700 mm in the north to about 35 mm in the south (the City of Eilat). The central part gets about 500 mm of rain. Water use in Israel is based on supply from four main resources (Table 2). Actually, the amounts of available waters according to Table 2 are smaller, 80–90% of the given values. That is due to the reduction in precipitation and the need to recover the past accumulated deficits in the water resources (Fig. 1). The gap in water availability is now gradually closed by putting into use desalinated sea water. Currently, around 300 million m^3 are produced annually by sea water desalination where the ultimate goal is to reach production of around 750 million m^3 per year. About 6% of available water is consumed by the industry; up to 30% is allocated to municipal needs; and around 64% to the agriculture sector and "green needs". Under drought and water scarce conditions, the agriculture sector is the "boxing bag". During the last years (2005–2012), available water amounts decreased to about 1,000 million m^3 per year, subject to climate changes. These new conditions enhanced the reuse of treated domestic wastewater and construction of new sea water desalination plants for future anticipated situations.

Annual volume of wastewater produced in Israel is about 575 MCM and around 65% of it is reused for crops irrigation. Negligible amounts are disposed uncontrolled to public sites and the rest is diverted to the coastal aquifer in the framework of further SAT

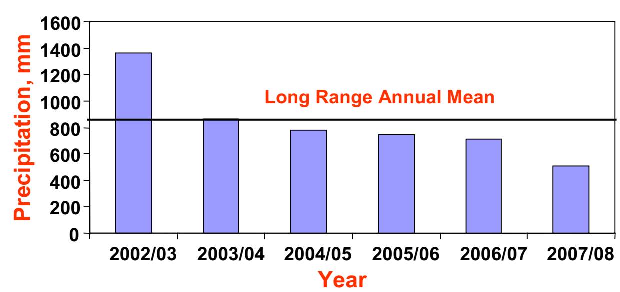

Fig. 1. Annual precipitation changes in Northern Golan Heights contributing water to the sea of Galilee and indicate the impact of climate changes on water available.

Table 2
Main water sources (MCM/year) in Israel according to the period of 1993–2008 (approximate values-adapted from the official site of the Water and Sewage Authority of Israel)

Water source	Sea of Galilee (via the national carrier)	Coastal aquifer	Mountain aquifer	Western Galilee and Karmel	Total
Natural supply	580	310	360	170	1,420
Losses	25	15	45	35	120
Net availability	555	295	315	135	1,300

processes (e.g. The Dan Region Project). Israel is currently operating close to 400 WWTPs. The treated effluent is used for diverse agriculture irrigation, green purposes and ornamental projects, primarily via Onsurface Drip Irrigation (ODI) and in smaller areas via SDI. Subsurface Drip Irrigation (SDI) has a series of agronomical, technical-wise and water use efficiency advantages. The corresponding figure for effluent reuse in the USA is around 1% [23]. In 2004, it is estimated that 700 Mm^3/y of water was reused in Europe which is less than a third of the estimated potential for water reuse [24]. The extended period of water shortage enhanced producing new waters via sea water desalination. These large amounts look promising, however, deceiving: it does not consider the deficits of water in the Sea of Galilee (700×10^6 m^3 in the year 2012) and the Dead Sea that are close to 8,000 MCM (the year 2012).

2.3. Italy

The climate in Italy is diverse, being sub-humid or humid (Alps mountain ridges) in the northern areas with precipitations in the range 800–1,350 mm/year and a mean temperature of 13˚C, and semi-arid in the south, with precipitation ranging from 450 to 600 mm/year and with a mean temperature of 18˚C. Therefore, this part of the country suffers frequently from droughts. Generally, the availability of water is copious and higher than that of other Mediterranean countries [25,26]. However, many parts of the Italian territory are susceptible to desertification, even due to human activities that involve an irrational exploitation of the territory. In fact, according to the project Desertification Information System for the Mediterranean, approximately 30% of Italian territory can be subject to the risk of desertification. In Italy, 60% of the fresh water withdrawn is used for agriculture. However, according to the data of the Italian Association of the Consortia for Land Remediation, only 0.3% officially comes from treated wastewater, even though a large portion (around 80%) of the water is used for domestic and industrial purposes and is subsequently treated in WWTPs [27]. In Italy, there are around 15,000 WWTPs, 70% of which have a size smaller than 2,000 People Equivalent (PE). The major part of the pollutant loading is then treated in larger WWTPs, with a treatment capacity larger than 100,000 PE. The reuse of wastewater is regulated by the Ministerial Decree, initiated on 2 May 2006 (further to the art 99 Law Decree 159/2006). Specified guidelines for treated wastewater reuse are based on the following:

- Agricultural uses: irrigation of crops for human consumption and livestock as well as any other non-food crops or for the irrigation of parks and gardens.
- Civil uses: use for streets flashing, feed of heating and cooling of industrial systems, feed of dual systems without any direct use in households (except for flushing toilets).
- Industrial uses: feed of cooling and heating systems, anti-fire net, production with the exclusion of food processing, and pharmaceuticals and cosmetics production.

The specific characteristics of treated water for water reuse are given in Table 3. Actually, the limit for *Escherichia coli* is often considered the actual bottleneck limiting the widespread application of wastewater reuse. In fact, in a survey of 1994 WWTPs carried out by FederGasAcqua (Federgasacqua is the organization gathering water and gas utilities in Italy) [28], it was shown how most of these plants hardly can meet the requested standards. These criteria refer to *E. coli*, suspended solids, oil and grease, phenols, chromium, detergents, nitrogen and phosphorus. More than 90% of the interviewed WWTPs managers stated that they were not able to meet the requested standards for one or more of the parameters. (Table 4).

Nowadays, most of the treated wastewater is reused for industrial purposes, and only a small portion for agricultural irrigation [27]. Wastewater treatment and reuse is generally applied in medium-large WWTPs (always larger than 40,000 PE) and the costs for effluent is in the range of 0.08–0.48 $/m^3$ with typical values of around 0.25 $/m^3$. These costs are absolutely out of range if compared to the costs for groundwater (just 0.03 $/m^3$ for pumping). Conclusively, the treated wastewater effluent cost is close to eight folds (0.25/0.03) higher in average per m^3, compared to the groundwater cost. Due to the low groundwater costs, it is particularly difficult to find a market of end-users for the reclaimed effluent (Table 5).

2.4. Cyprus

2.4.1. Location, population and climate

Mean annual temperature during 2001–2010 was about 20˚C, while for the last 10 hydro-meteorological years the average annual rainfall was about 475 mm/year with the lowest rainfall of 272 mm/year taking place during 2007–2008 and the highest (604 mm/year) during 2001–2002 [29]. According to data of the national Meteorological Service, mean annual

Table 3
Chemical, physical and microbiological characteristics for effluent reuse in Italy (regulation from 2 May 2006)

Parameter	Measured unit	Limit
pH	–	6.0–9.5
SAR*	$(mmol/L)^{0.5}$	<10
Coarse materials		Absent
Total suspended solids	mg/L	10
BOD_5	mgO_2/L	20
COD	mgO_2/L	100
Total phosphorous	mgP/L	2
Total nitrogen	mgN/L	15
Ammonia	$mgNH_4^+/L$	2
Electric conductivity	μS/cm	3,000
Al	mg/L	1
As	mg/L	0.02
Ba	mg/L	10
Be	mg/L	0.1
B	mg/L	1.0
Cd	mg/L	0.005
Co	mg/L	0.05
CrVI	mg/L	0.005
Fe	mg/L	2
Mn	mg/L	0.2
Hg	mg/L	0.001
Ni	mg/L	0.2
Pb	mg/L	0.1
Cu	mg/L	1
Se	mg/L	0.01
Sn	mg/L	3
Ta	mg/L	0.001
Va	mg/L	0.1
Zn	mg/L	0.5
Total cyanides (as CN)	mg/L	0.05
Sulphite	$mgSO_3/L$	0.5
Sulphate	$mgSO_4/L$	500
Free chlorine	mg/L	0.2
Chloride	mg/L	250
Fluoride	mg/L	1.5
Oils and greases	mg/L	10
Mineral oils (note I)	mg/L	0.05
Total phenols	mg/L	0.1
Penta-chloro-phenol	mg/L	0.003
Total aldehyde	mg/L	0.5
Tetrachloroethylene, trichloroetylene	mg/L	0.01
Total chlorine solvents	mg/L	0.04
Tri-halo-methane (THM)	mg/L	0.03
Total aromatic organic solvents	mg/L	0.01
Benzene	mg/L	0.001
Benzo(a)pyrene	mg/L	0.00001
Total N-organic solvents	mg/L	0.01
Total detergents	mg/L	0.5
Chlorine pesticides (each one) (note II)	mg/L	0.0001
Phosphorous pesticides (each)	mg/L	0.0001
Other total pesticides	mg/L	0.05
Escherichia coli (note III)	UFC/100 mL	10 (80% samples) 100 max.
Salmonella		Absent

*SAR: Sodium Adsorption Ratio = $[Na]/(\{[Ca]+[Mg]\}/2)^{0.5}$ with molar concentrations.
Note I: This parameter should reach a value below the limit of detection when the direct discharge on soil is used.
Note II: The parameter is referred to any single compound.
Note III: this value is 50 CFU/100 mL (80% of the samples) and 200 CFU/100 mL (max acceptable level) when considering the effluent from lagoons and wet-ponds.

Table 4
Typical characteristics of the raw and treated wastewater for conventional pollutant parameters (Italy) (mg L^{-1})

Quality parameter	Influent	CASP effluent	MBR1 effluent	MBR2 effluent
Total suspended solids (TSS)	226	10	<1	<1
Chemical oxygen demand (COD)	295	104	40	19
Soluble COD (SCOD)	110	64	39	19
Readily biodegradable COD (RBCOD)	38	–	–	–
Total Kjeldahl nitrogen (TKN)	42	1.5	0.3	2.0
NH_4-N	25	0.1	0.2	0.5
NO_3-N	1.2	7.8	5.9	11.3
Total P	4.0	1.0	0.9	1.1
Phosphate P (PO_4)	1.2	0.5	0.4	0.5

precipitation in Cyprus within the twentieth century showed a falling trend of approximately 1 mm per year, with precipitation levels to be significantly lower over the second half of the century.

2.4.2. Water resources in Cyprus

The amount of water, which corresponds to the total surface of the government controlled area, is

Table 5
Water resources facts and water uses of surface water and groundwater [30]

Water facts	Quantity (Mm^3)
Water corresponding to the total surface of the government controlled area	2,804
Inflow (surface and groundwater)	280
Annual loss of water to the sea as groundwater seepage	61
Water use	
Average annual surface water used for irrigation	35
Average annual surface water used for domestic use (after treatment)	21
Average annual surface water used for recharge	9
Groundwater extraction	146
Groundwater used for agriculture	120
Groundwater used for domestic purposes	26

2,804 Mm^3. Only 10% (280 Mm^3) is considered as inflow since the remaining 90% returns to the atmosphere through evapotranspiration. The mean annual quantity of 280 Mm^3 of water is distributed as 30% surface water and 70% ground water. An average of 61 Mm^3 is lost to the sea every year, mainly as groundwater seepage.

Concerning surface water, the average annual inflow to the main dams is about 80 Mm^3, while the total is around 290 Mm^3. Groundwater extractions is estimated to be about 146 Mm^3 on an average annual basis. This figure does not correspond to the sustainable yield of the aquifers, which is much lower. During the dry year of 2008, the contribution to irrigation of all dams was only 8.0 Mm^3 and necessitated the need to import water from Greece. The main uses both for surface water and groundwater as well as the respective quantities are presented in Table 5 [30].

Agriculture, domestic and industry utilization are the main economic sectors of water demand. Water demand for agriculture is around 170 Mm^3 (65%), and for domestic and industrial use is 90 Mm^3 (35%). It is estimated that the water demand in the government-controlled areas will increase from 260 Mm^3 in 2010 to 275 Mm^3 in 2020, thus an increase of 15 Mm^3 is expected. Desalination units at present contribute up to 50 Mm^3 per year. Tertiary-treated wastewater is used to satisfy part of the existing irrigation needs. Specifically, about 15 Mm^3 of treated wastewater are being produced, from which about 80% is directly reused for irrigation and groundwater recharge. It is estimated that by 2025, more than 80 Mm^3 treated wastewater will be produced due to the construction and operation of more WWTPs, in line with the Urban Wastewater Directive 91/271/EEC of the European Union [30].

2.4.3. Wastewater treatment and reuse in Cyprus

There are seven main urban WWTPs serving the big urban centres (larger than 10,000 PE) of the island. Six plants serve municipalities with PE of 2,000–10,000, five plants serve communities with PE below 2,000, four plants serve refugee housings, five

Table 6
Specifications for the quality of treated water for irrigation purposes for WWTPs below 2,000 PE [33]

No.	Type of crops	BOD mg/L	Suspended solids, mg/L	Faecal coliforms/100 mL	Intestinal worms/L***
1	All crops and green amenity areas of frequent public access[a]	10*	10*	5* 15**	Nil
2	Vegetables eaten cooked[b]	10* 15**	10* 15**	50* 100**	Nil
3	Crops for human consumption and green amenity areas of limited access	20* 30**	30* 45**	200* 1,000*	Nil
4	Fodder crops	20* 30**	30* 45**	1,000* 5,000**	Nil
5	Industrial crops	50* 70**	–	3,000* 10,000**	–

*These values must not be exceeded for 80% of samples analyzed (number of samples: 24/year).
**Maximum value allowed.
***Samples taken once per year (summer months).
[a]Irrigation of leafy vegetables, bulbs and condyles eaten uncooked is not allowed.
[b]Potatoes, beetroots, colocasia.

Table 7
Effluent quality characteristics included in disposal permits for sewage treatment plants above 2,000 PE [30]

No.	Parameters for treated effluent	Maximum limits
1	BOD_5 (mg/L)	10 mg/L
2	COD (mg/L)	70 mg/L
3	Suspended solids (SS) (mg/L)	10 mg/L
4	Conductivity (μS/cm)	2,200 μS/cm
5	Total nitrogen (TN) (mg/L)	15 mg/L*
6	Total phosphorous (TP) (mg/L)	10 mg/L**
7	Chlorides (Cl) (mg/L)	300 mg/L
8	FOG (mg/L)	5 mg/L
9	Zinc (Zn) (mg/L)	1 mg/L***
10	Copper (Cu) (mg/L)	0.1 mg/L
11	Lead(Pb) (mg/L)	0.15 mg/L
12	Cadmium (Cd) (mg/L)	0.01 mg/L
13	Mercury (Hg) (mg/L	0.005 mg/L
14	Chromium (Cr) (mg/L)	0.1 mg/L
15	Nickel (Ni) (mg/L)	0.2 mg/L
16	Boron (B) (mg/L)	0.75 mg/L
17	*E. Coli*	50 E.Coli/100 mL
18	Eggs of intestinal worms	Nill
19	Residual chlorine (mg/L)	1 mg/L****
20	pH	6.5–8.5

*For discharge in sensitive areas and into the sea maximum level 10 mg/L.
**For discharge in sensitive areas and into the sea maximum level 2 mg/L.
***For discharge into the sea maximum level 0.1 mg/L.
****For sensitive areas and discharge into the sea 0.5 mg/L.

plants serve hospitals and finally, nine plants serve military camps. Most of the plants apply tertiary treatment [30].

Treated effluent is used for crop irrigation, with the exception of leafy vegetables, bulbs eaten raw, as well as for grass and green amenity areas irrigation. Part of the treated effluent is used also for aquifer enrichment. The treated wastewater enters about 22 shallow ponds constructed by the Water Development Department and through infiltration reaches the aquifer. It should be noted that part of the treated effluent that is currently discharged into the sea is scheduled to be utilized for the enrichment of another aquifer, which has been brackish for some time due to the infiltration of seawater [30].

2.4.4. *Wastewater reuse standards in Cyprus*

According to Article 12 of Directive 91/271/EEC referring to Urban Wastewater Treatment, "treated wastewater shall be reused whenever appropriate" [31]. Based on the Code of Good Agricultural Practice issued with a decree within the framework of Cyprus Water Pollution Control Laws, the use of recycled wastewater of appropriate quantity is required and is an environmentally accepted solution, also given the dry climate of Cyprus and reduced rainfall [32]. Terms for waste disposal are applied to all urban WWTPs serving a capacity of PE of below 2,000 residents. Based on these, treated wastewater could be reused for irrigation or stored behind reservoirs for further use. The exact areas to be irrigated need to be identified and disposal and use of treated wastewater should be in accordance to the code of good agricultural practice. The quality characteristics of treated wastewater used for irrigation are shown in Table 6.

Treated wastewater that will be used for irrigation must not contain toxic elements or compounds which on their own or in combination are accumulated on the edible parts of the plant and have been proven to be toxic for humans. During the winter period, treated effluent should be stored in a storage tank of a capacity equal to the wastewater quantity for at least 10 days. In case treated wastewater is disposed in dams, this should be allowed only in cases the when water is used for irrigation purposes. Effluent disposal is not allowed in cases when the water is used for drinking purposes and should not exceed 5% of the water stored during the disposal. Toxicity inspection must take place four times per year or less frequently when the conditions allow it and Gene-toxicity inspection at least once per year [33].

For WWTPs above 2,000 PE, the quality characteristics of recycled water are included in the terms of disposal permits. These are shown in Table 7. Information on the frequency of analyses is also included in the disposal permits.

3. Wastewater research in progress in the target countries

Current paper reviews the wastewater issues in different target countries. Investigations in Greece focus on the accumulation of heavy metals, while in Israel, risk assessment is of major interest. Advanced treatment technologies are of high importance in Italy, while in Cyprus the focus has been set on xenobiotics.

3.1. *Wastewater research progress in Greece*

Current investigations are focusing on the irrigation of forest species, and food crops (vegetables), especially on their edible components. The purposes of these investigations are as follows:

- To assess the response of forest species to heavy metals of wastewater and sludge reuse and to set pollution indices.

Table 8
Maximum contaminant level-Inhbar-criteria

Parameter	Units	Unrestricted irrigation	Streams
(a) Israel			
Electrical conductivity (EC)	dS/m	1.4	–
BOD_5	mg/L	10	10
TSS	mg/L	10	10
COD	mg/L	100	70
Nitrogen (Ammonia)	mg/L	20	1.5
Total nitrogen	mg/L	25	10
Total phosphate	mg/L	5	1.0
Chlorides	mg/L	250	400
Fluorides	mg/L	2	
Sodium	mg/L	150	200
Fecal coliform	CFU/ 100 ml	10	200
Dissolved oxygen	mg/L	0.5<	3<
pH		6.5–8.5	7.0–8.5
Mineral oil	mg/L		1
Residual chlorine	mg/L	1	<0.05
Anionic surfactant	mg/L	2	0.5
SAR	$(mmol/L)^{0.5}$	5	
Boron	mg/L	0.4	
Arsen	mg/L	0.1	0.1
Mercury	mg/L	0.002	0.0005
Chromium	mg/L	0.1	0.05
Nickel	mg/L	0.2	0.05
Selenium	mg/L	0.02	
Lead	mg/L	0.1	0.008
Cadmium	mg/L	0.01	0.005
Zinc	mg/L	2	0.2
Iron	mg/L	2	
Copper	mg/L	0.2	0.02
Manganese	mg/L	0.2	
Aluminum	mg/L	5	
Molybdenum	mg/L	0.01	
Vanadium	mg/L	0.1	
(b) Greece			
Aluminum (Al)	mg/L	5	
Arsenic (As)	mg/L	0.1	
Beryllium (Be)	mg/L	0.1	
Cadmium (Cd)	mg/L	0.01	
Cobalt (Co)	mg/L	0.05	
Chromium (Cr)	mg/L	0.1	
Copper (Cu)	mg/L	0.2	
Fluorine (F)	mg/L	1.0	
Iron (Fe)	mg/L	3.0	
Lithium (Li)	mg/L	2.5	
Manganese (Mn)	mg/L	0.2	
Molybdenum (Mo)	mg/L	0.01	
Nickel (Ni)	mg/L	0.2	
Lead (Pb)	mg/L	**0.1**	
Selenium (Se)	mg/L	0.02	
Vanadium (V)	mg/L	0.1	
Zinc (Zn)	mg/L	2.0	
Mercury (Hg)	mg/L	0.002	

(*Continued*)

Table 8
(*Continued*)

Parameter	Units	Unrestricted irrigation	Streams
Boron (B)	mg/L	2	
Escherichia coli	(EC/100 mL)	≤5 for 80% of the samples and ≤50 for 95% of the samples	
BOD_5	mg/L	≤10 for 80% of the samples	
SS	mg/L	≤10 for 80% of the samples	
Turbidity	NTU	≤2 median value	
(c) Cyprus			
Aluminum (Al)	mg/L	5.0	
Arsenic (As)	mg/L	0.1	
Beryllium (Be)	mg/L	0.1	
Cadmium (Cd)	mg/L	0.01	
Cobalt (Co)	mg/L	0.05	
Chromium III (Cr)	mg/L	0.1	
Copper (Cu)	mg/L	0.2	
Iron (Fe)	mg/L	5.0	
Lithium (Li)	mg/L	2.5	
Manganese (Mn)	mg/L	0.2	
Molybdenum (Mo)	mg/L	0.01	
Nickel (Ni)	mg/L	0.2	
Lead (Pb)	mg/L	5.0	
Selenium (Se)	mg/L	0.02	
Vanadium (V)	mg/L	2.0	
Zinc (Zn)	mg/L	0.005	
Boron (B)	mg/L	0.75	
Escherichia coli	(EC/100 mL)	≤5 for 80% of the samples and ≤ 50 for 95% of the samples	
BOD_5	mg/L	≤10 for 80% of the samples	
SS	mg/L	≤10 for 80% of the samples	
Turbidity	NTU	≤2 median value	

- To examine the effect of the treated wastewater on the accumulation of heavy metals in soil and in the various plant parts, with emphasis on the edible ones.
- To develop management models allowing to asses most suitable regions for wastewater reuse, by means of the so-called multi-criteria analysis for the effluent and sludge reuse.

Wastewater treatment by means of natural systems is in progress in Greece. The results obtained so far have helped to disseminate this method of natural wastewater treatment in many communities of Northern Greece. Different aspects of natural systems have so far been studied, which are summarized below:

- Comparative design performance [34].
- Sludge accumulation pattern in an anaerobic pond [35].
- Modelling the temperature pattern of a covered anaerobic pond with computational fluid dynamics [36].
- Evaluation of the performance of a slow sand-filter in a pilot-scale wastewater stabilization pond system [37].
- Wastewater Stabilization Ponds system of thermal stratification [37].
- Wastewater effect on sea water, treatment methods and quality [38].
- Methods for the treatment of sewage sludge [39].
- Cost and benefits of the alternative strategies for treating wastewater [40].

3.1.1. *Accumulation of heavy metals in forest species and food plants*

The WWTP reuse has been tested extensively in various forest and food plant species especially in relation to the uptake and accumulation of heavy metals [39,41,42]. Emphasis has been given to the capacity of certain Mediterranean forest species (*Myoporum* sp., *Nerium oleander, and Geranium* sp.) to absorb and accumulate heavy metals (Cu, Mn and Zn).

3.1.2. Assessment of the heavy metal pollution of soils

The current research is also related to establishing new, less complex and easily calculated indices, for the assessment of heavy metal soil pollution level. The new indices that have been proposed are the following [43]:

(1) The elemental pollution index (EPI):

$$\mathrm{EPI} = \sqrt[n]{M_1 \times M_2 \times M_3, \ldots, M_n} \tag{1}$$

where: M_1, M_2, …, M_n are the respective heavy metals in mg/kg soil.

(i) Heavy metal load (HML)

$$\mathrm{HML} = M_1 + M_2 + M_3,\ M_n \tag{2}$$

where M_1, M_2, …M_n the respective heavy metals in mg/kg soil, and

(ii) Total concentration factor (TCF)

$$\mathrm{TCF} = \frac{(M_1 + M_2 + M_3 + \ldots M_n)}{(M_1/M_{1r} + M_2/M_{2r} + M_3/M_{3r} \ldots M_n/M_{nr})} \tag{3}$$

where: M_1, M_2, M_3, …,M_n are the respective heavy metals, and M_{1r}, M_{2r}, M_{3r},…,M_{nr} are the corresponding reference values of these metals. The concentration of the respective metals is shown in mg/kg soil.

The temporary critical values found for these indices are: EPI = 0.5, HML = 13.6 and TCF = 2.40.

The above indices have been compared and graded with Pollution Load Index (PLI) which was used as a reference point. The PLI is accepted by most researchers as a trustworthy index for the evaluation of soil heavy metal pollution [44]. Therefore, the proposed new indices can be used successfully for soil pollution assessment. Similarly, current research work which is under progress also concerns the use of zeolite along with the application of sludge, as a means for alleviating the heavy metal toxic effects of long-term sludge on plant growth.

3.2. Advances in wastewater research in Israel

3.2.1. The risk assessment approach for safe effluent application

The research on the wastewater application for crop irrigation includes the risk posed on humans during effluent application and related characteristics [45,46]. These risks include the following: (i) the kind of fruits/vegetables (e.g. nuts vs. on-ground strawberry) which is irrigated with the effluent and related parts consumed raw (peeled or consumed entirely); (ii) the elapsed time between last watering shift and timing of harvesting and/or consumption; (iii) the influent quality, treatment level and quality of applied effluent; (iv) the consumer characteristics given by the weight, amount of fruits/vegetables consumed per day and fraction eaten raw, immunity level and heredity properties, sanitary conditions and general health environment, and; (v) the irrigation application method, overhead spraying or sprinkling, ODI or SDI which differ in potential contact with the agriculture consumed products. Risk assessment management model is used to emphasize the role of the effective variables on human health. The risk can be solved by applying the effluent via SDI and keeping a specific time difference between last irrigation and harvesting.

3.2.2. Exposure characteristics combined with dose-response reaction

The model used for the exposure route of the pathogens is based on a human adult where the dietary intake consists of fruits and vegetables irrigated with domestic treated effluent. Other related assumptions include: (i) exposure through ingestion only; (ii) virus concentration in raw wastewater is log-normally distributed (e.g. a common virus arithmetic mean in effluent is 1,000 Plaque Forming Units per liter (PFU/L), and the standard deviation is 300 PFU/L [47,48]; (iii) the elapsed time after last effluent application (or storage detention) is a complementary part of the treatment; (iv) no cross-contamination of fruits and vegetables after harvesting is considered; and (v) it is common that the public consume around 50% of their diet uncooked, unpeeled and unwashed [49]. Some essential results and related consequences are given in Fig. 2.

3.2.3. Nanotechnology for dissolved constituents removal from secondary effluent

Field studies are in progress with an advanced pilot experimental nanotechnology system (around 120 m^3/day) for unrestricted wastewater reuse. The pilot membrane system consists of in series ultra filtration (UF) and reverse osmosis (RO) membranes, with similar configuration and accessories [50]. The membranes are placed into a container and operated according to the water demand for irrigation. The UF membrane consists of two 4-inch pressure vessels made of composite material having a pressure resistance of up to 150 psi. Each vessel holds two spiral-wound membranes having a molecular weight cutoff of 20 k Dalton and 0.01 micron apertures. The designed permeate capacity is 0.5–0.8 m^3/h. The primary applications of UF are for the removal of micro-organisms and organic matter. Virus size range is 0.02–0.08 μm, followed by bacteria (0.5–10 μm), protozoan cysts and oocytes (3–15 μm). RO is traditionally employed for removal of salts from brackish and seawater. In the experimented system, the RO consists of a 4-inch pressure vessel made of a composite material having a pressure resistance of up to 400 psi. The vessel holds two 4-inch thin film polyamide spiral-wound membranes. A sample of the effluent quality after the nanotechnology treatment stage is given in Table 9.

3.3. Advances in wastewater reuse in Italy

3.3.1. Advanced technologies for wastewater reclamation and reuse

An interesting number of studies (mainly by the Italian research groups) focused on application of advanced technologies, like the Membrane BioReactor (MBR), for the effective removal of several classes of pollutants, from heavy metals to aromatic hydrocarbons and chlorinated micro-pollutants, as well as detergents and pesticides. We recently reviewed [51] several years of studies on the application of the MBR technology for the removal of target compounds. The results compare between a Conventional Activated Sludge Process (CASP) and a MBR in terms of effluent quality. Table 9 presents sample results, where addi-

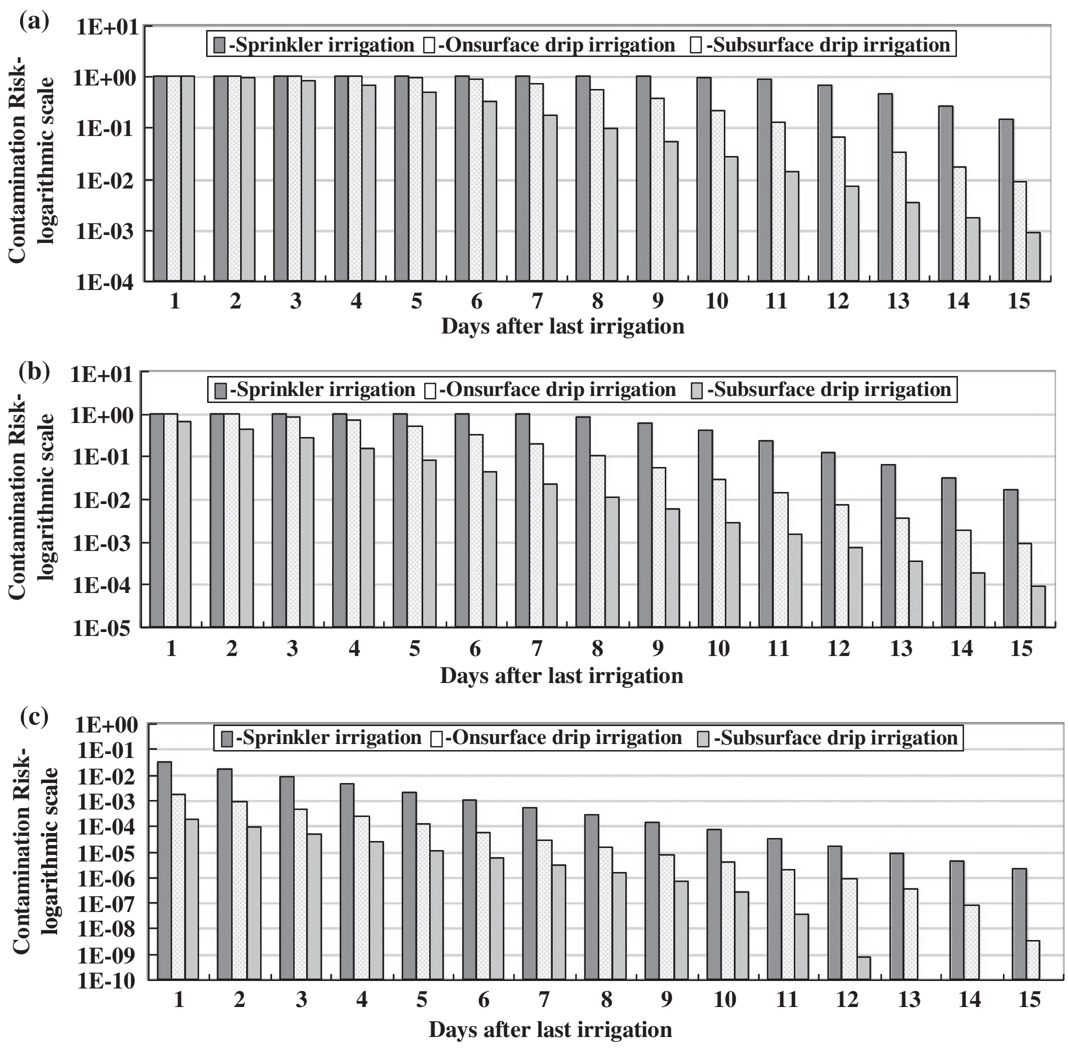

Fig. 2. Contamination risk behaviuor after irrigation regarding water treatment: (a) primary effluent; (b) secondary effluent; (c) advanced treatment.

tional data can be found in the different publications: metals removal [52], nutrients removal [53,54], micro-pollutants, dioxins/furans and poly-chlorinated biphenyls [55], volatile organic carbon compounds and polycyclic aromatic hydrocarbons [56,57].

3.4. Developments in wastewater quality in Cyprus

3.4.1. Research on the removal of urban wastewater organic xenobiotics

It is widely accepted that currently applied treatment for urban wastewater failed to remove, to some extent, recalcitrant xenophobic compounds and endocrine disrupting compounds while these parameters are not included in the guidelines issued for the use of reclaimed wastewater. Due to the long-term reuse of treated wastewater, uptake of organic xenobiotic nutrients and heavy metals by soil and plants as well as release of antibiotic resistant genes in the environment need to be carefully studied in order to safeguard human health and the environmental ecosystems [58]. The existence and fate of pharmaceuticals have received considerable attention by the scientific community; since their quantification is not standardised, the degree of their removal with various methods and under different experimental conditions is investigated while their potential effects on the environment and toxicity have not clearly been defined. Towards this direction, the research groups of NIREAS-International Water Research Centre and GAIA-Laboratory of Environmental Engineering of the University of Cyprus have been working on laboratory and pilot-scale experiments related to the removal of various pharmaceuticals from wastewater.

In order to identify the removal potential of pharmaceutical compounds in wastewater effluents, a number of bench-scale experiments have been conducted focusing on the use of Advanced Oxidation Processes (AOPs). AOPs are broadly defined as aqueous phase oxidation methods based on the intermediary of hydroxyl or other radicals to oxidize the target pollutants and can be employed either alone or combined with other processes; either as pre-treatment or post-treatment stage [59]. Among the experiments conducted, TiO_2 photocatalysis was applied in order to investigate the removal potential of amoxicillin, carbamazepine and diclofenac [60], diclofenac [61], the antibiotic sulfamethoxazole [62] and ofloxacin and atenolol [63]. Solar TiO_2 photo-catalytic treatment of atenolol and propranolol [64] and the fluoro quinolone ofloxacin [65] was also studied. Based on the work conducted, it is evident that the degree of degradation depends on many factors, namely: (i) the target compound and concentration; (ii) irradiation time; (iii) photo catalyst type and loading; (iv) the presence of electron acceptor; and (v) the presence of extra hydroxyl radical sources. Furthermore, the degradation of pharmaceutical compounds is not always favoured at near-neutral pH values which are typical of real wastewater matrices. In addition, it has been shown that in most cases toxicity can only be reduced or even vanished while in some cases degradation by-products appear to be more toxic than the pharmaceutical itself.

Photo-Fenton experiments under simulated solar radiation have been also conducted. Solar Fenton for the removal of ofloxacin has been proved to be more effective than the solar TiO_2 process [65]. It was also proved an effective technology for the fast removal of estrogens hormones; achieving, however, only partial removal of the estrogenicity [66].

4. Health protection measures

Conducting an analysis of any existing or proposed wastewater irrigation system will identify the key risk points, and this is an important step in identifying which health-protection measures are likely to be appropriate. Health impact assessment will also help to identify health hazards and risk factors that may arise due wastewater use in agriculture; this will provide a context for the formulation of a public health action plan. The primary health hazards associated with the agricultural use of wastewater include pathogens and some chemicals present in the wastewater. However, there are secondary risks that may arise from the creation of habitats that facilitate the survival and breeding of vectors and a subsequent

Table 9
Effluent analysis at three stages of treatment Arad site, Israel

Treatment stage mg/L	BOD mg O_2/L	COD mg O_2/L	pH	Fecal coliforms CFU/100 mL	EC	TDS dS/m	N-NH_4 mg/L	PO_4 mg/L
Secondary effl.	105	640	7.8	7.2×10^5	1.81	110	41.9	25.8
UF permeate	2	106	7.7	4	1.78	6	52.1	7.8
RO permeate	0.1	1.4	6.2	0	0.11	0	3.0	0.8

increase in the transmission of vector-borne diseases in wastewater-irrigated areas.

The health-based target of a tolerable additional burden of disease of ≤ 10^{-6} Disability-Adjusted Life Year per person per year can be achieved when treated wastewater is used for crop irrigation, by a combination of health-protection measures that produces an overall pathogen reduction of 6–7 log units. These control measures include: (i) crop restriction; (ii) wastewater application techniques; (iii) pathogen die-off between last irrigation and consumption; (iv) food preparation measures (washing, disinfecting, peeling and cooking); (v) human exposure control; and (vi) wastewater treatment.

The feasibility and efficacy of health protection measures will depend on several factors, including: (i) availability of resources (labour, funds, land and water); (ii) existing social and agricultural practices; (iii) market demand for wastewater-irrigated food and non-food crops; (iv) existing patterns of excreta-related disease; and (v) institutional capacity and jurisdiction to ensure the efficacy of selected health protection measures [67].

Maximum contaminant level criteria are shown in Table 8 for Israel, Greece and Cyprus, respectively.

5. Summary and discussion

The data presented in the present review are derived from the selected target countries of the study, and thus do not aim to provide a full picture of current conditions in all Mediterranean countries. The progress on wastewater research in each of the studied countries presents particularities and special focus is given on different aspects of wastewater research in each country. The presentation of data from all target countries in a unified mode was not always possible, based on available data, and this was a limitation of the present study.

Based on the above, the following conclusions can be drawn:

- Treatment and reuse strategies have to be effective and to comply with future needs of high-quality effluent for unrestricted utilization.
- Natural treatment systems are effective, however, depend to a large extent on land availability.
- Future research has to consider elemental interactions of soils, plants and effluent quality, taking into account the value of the sludge that is obtained in the treatment facilities.
- Disinfection and equivalent effective methods for pathogens removal is an integrative component of effluent reuse.
- The PLI, Concentration Factor and indirectly monitoring of Transfer Factor can be implemented for pollution assessment.
- Management modelling such as utilizing the exposure route model allows successful risk assessment of pathogen's removal during effluent reclamation.
- Nanotechnology is probably the forthcoming method for the removal of pathogens and dissolved components from the effluent.
- MBR is the forthcoming technology for wastewater treatment for unrestricted reuse.

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