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Use of waste stabilization ponds' systems in Mediterranean Europe

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ABSTRACT

This paper is a review of the use of waste stabilization ponds (WSPs) systems in Mediterranean Europe. More specifically, it aims at registering the situation and the efficiency of waste stabilization ponds' systems in Greece, Italy, Spain, Portugal, France, and Cyprus. For that reason, the systems' efficiency for the removal of suspended solids (SS), BOD_5, COD, N-total, $N\text{-}NH_4$, P-total, and *F. coliforms* is estimated. The possibility of effluents' reuse, according to their quality, is also examined. All the aforementioned countries were selected because they have similar climate and they are all European Union member states: therefore, any differences in waste stabilization ponds' popularity and efficiency as well as in the legislation regarding the reuse of the ponds' effluents is also interesting. In Greece, the use of waste stabilization ponds is limited and although most of the existing ponds are not adequately designed, constructed, operated, and maintained, the systems' efficiency is satisfactory.

Keywords: Waste stabilization ponds; Efficiency; Urban wastewater; Mediterranean Europe; Effluents reuse

1. Introduction

Waste stabilization ponds (WSPs) are widely used all over the world for the treatment of both urban and industrial wastewater. They are characterized by their simplicity, low cost, and effectiveness. A World Bank Report endorsed the concept of stabilization ponds as the most suitable wastewater treatment method for effluent reuse in agriculture [1]. Stabilization ponds are the preferred wastewater treatment process in developing countries, where land is often available at reasonably low cost and skilled labor is in short supply. In Europe, waste stabilization ponds are widely used, especially for small rural communities, serving populations up to 2,000 e.p. approximately. In many Mediterranean countries, larger systems do exist (for example, in Mediterranean France and also in Cyprus, Spain, and Portugal), providing a popular urban wastewater treatment method [2]; however, in Greece, their use is limited [3].

2. Design references, current situation, and effluent quality

2.1. Greece

Only a few waste stabilization ponds' systems exist in Greece, representing just 8% of all urban wastewater treatment plants (UWWTPs) in the country. It is worth

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mentioning that 90% of those systems are situated in North Greece, serving populations ranging from 500 up to 4,000 e.p. in rural regions (Table 1). The 76% of them are located in the Region of Serres [3].

The first natural system in Greece for the treatment of wastewater was constructed in the Region of Serres (Sitohori) in 1982 [3]. At the same region, 10 more similar systems were constructed (500–3,000 e.p.), but only seven of them are in operation nowadays; the rest of them were abandoned (Table 1) [4]. All the aforementioned systems receive domestic wastewater and there is no planning for any industrial effluent treatment in the future. They were all designed based on the same assumptions: daily flow rate 120 L/e.p/d, influent organic load BOD_5 45 g/p/d, influent suspended solids (SS) 60 g/p/d, influent *T. coliforms* 5×10^6/100 ml, detention time in the first pond 15–30 days for 30% BOD_5 removal, solids concentration at the bottom 6%, and removal of the sludge every 5 years. For the maturation ponds' design, the detention time was chosen as 8 days, with the effluent's required characteristics as follows: BOD_5 30 mg/L and *T. coliforms* 5,000/100 ml. The studies proposed for every system the construction of a facultative pond with a depth of 2.40–2.50 m and three maturation ponds with a depth of 1.50 m as well as the placement of rock filter before the final effluent discharge for algae filtration. The suggested rock filter should have

Table 1
The WSPs in North Greece

Region	Year of operation	Capacity e.p.[a]	Ponds[b]	Situation
Prefecture of Serres				
Ano Poroia	1992	2,000	F.M.M.RF.	In operation
Vamvakofito	1989	2,000	F.M.M.RF.	In operation
Therma	1989	600	F.M.	In operation
Ivira	2007	800	F.M.M.M.RF.	In operation
Leukothea	1987	500	F.M.	In operation
Maurolofos	1991	500	F.M.	Out of use
Mesorahi	1999	500	F.M.M.	Out of use
N. Skopos	1980	1,000	F.M.M.	In operation
Pentapoli	1989	3,000	F.M.M.	Out of use
Sitohori	1982	1,000	F.M.M.	Out of use
Charopo	1994	2,300	F.M.M.	In operation
Prefecture of Kavala				
Kokkinohoma 1	1995	900	F.M.M.RF.	In operation
Kokkinohoma 2	1998	900	F.M.M.RF.	In operation
Prefecture of Thessaloniki (pilot plant, for irrigation reuse)				
Sindos 1	1996	200	A.F.M.M.M.RF.	In operation
Sindos 2	1996	600	A.F.M.M.RF.	In operation
Sindos 3	1996	330	F.M.M.RF.	In operation
Prefecture of Florina				
Vegora	2001	800	A.F.M.M.RF.	In operation
Faragi	2001	400	A.F.M.M.RF.	In operation
12 WSPs	2011	400–800	A[1].F.M[2].M[2].RF.	
Island of Limnos				
Moudros	2002	4,000	2A[1].F.M[2].M[2].RF.	In operation
Prefecture of Xanthi				
SEVATH[3]	1985	Industrial	2 Aerated, M.	Out of use

[a]Of study.
[b]A: Anaerobic, F: Facultative, M: Maturation, RF: Rock filter.
[1]Covered concrete anaerobic pond /[2]Lined with geomembrane /[3]Tomato processing factory, which is now closed.

Table 2
Average reported measurements for the influent and effluent of WSP systems in Mediterranean Europe

Region	North Greece ($n = 10$)		South France ($n = 178$)		Catalonia-Spain ($n = 7$)	
Parameter	Influent	Effluent	Influent	Effluent	Influent	Effluent
BOD (mg/l)	316	15	277	23	280	67
COD (mg/l)	647	97	657	99	–	–
SS (mg/l)	269	61	256	60	260	100
TN (mg/l)	78	19.5	70	22	100	33
NH_4 (mg/l)	65	12	48	14	–	–
TP (mg/l)	14.6	11.7	21	8.5	15	7.2
F.Coliforms (col/100 ml)	7.0×10^6	1.18×10^3	–	–	2.0×10^7	4.0×10^4

had a depth of 1.50 m and been filled with 15–75 mm diameter gravel. During the construction, some modifications occurred, mainly to the number and the dimensions of the ponds, resulting in smaller retention times than predicted. Most of the ponds were not lined with geomembrane—a compressed layer of clay was used instead—the only exception being one system, situated in the vicinity of hot springs. There is no recirculation in the systems and in most cases the sludge has not been removed during their operation. Wastewater is collected through the existing combined (multi-flow) sewer systems and through the main pipes connected to the ponds. The outflow takes place almost superficially. Generally, the construction, operation of the inflow's works, maintenance of the ponds, and following of the safety rules are considered inadequate [4–6].

The performance of WSPs in Greece is generally good. The concentration of inorganic elements and heavy metals in both influents and effluents were insignificant (Table 2) [4,7].

2.2. Cyprus

In arid and semi-arid regions, there is scarcity of water and the use of treated wastewater for irrigation is an efficient way of conserving fresh valuable water resources. There is a great number of urban wastewater treatment plants in Cyprus, constantly upgrading; however, the use of WSPs is very limited [8]. Still, WSPs are used for the treatment of wastewater at both urban and rural regions. It is estimated that until 2012, the existing sewerage system and the two treatment plants of Nicosia (Anthoupolis and Mia Milia) (Table 3), will be able to completely cover the needs of the region, serving 300,000 e.p (50.000 m^3/d). The current systems of WSPs will be upgraded to tertiary plant while the construction of a new treatment plant in Vathia Gonia is also scheduled [9]. Cyprus uses the most advanced but also the most energy-consuming technology (i.e. aerated ponds).

2.3. France

France is the Mediterranean Europe country where WSPs are most widely used, with around 3,000 systems, which means, approximately 10 times more than Constructed Wetlands plants. The WSP systems represent 20% of total number of urban wastewater treatment plants in the country. Their use has significantly grown after 1970s. It is worth mentioning that some of the early WSP systems, installed in the mid-1970s, have replaced malfunctioning activated sludge units serving small communities (under 2,000 e.p.).

Table 3
The WSPs in Nicosia

Region	Capacity (m^3/d)	Ponds[a]	Situation	Effluent disposal
Anthoupoli	350	Aerated, F.F.M.	In operation	In a stream
Mia Milia (Haspolat WWTP)	15,000	5A.4AE.3F.4 M.	In operation	In river Pediaios
Kophinou[1]	N.F.I	2A	In operation	N.F.I
P. Kivides	N.F.I	N.F.I	In operation	For irrigation (trees)
Gerasa	N.F.I	N.F.I	In operation	In a river
Tersefanou	N.F.I	N.F.I	In operation	In a river

[a]A: Anaerobic, AE: Aerobic, F: Facultative, M: Maturation / N.F.I: No further information.
[1]Central slaughterhouse's wastewater.

That happened due to the simplicity of WSPs in operation and maintenance [10]. The WSPs generally serve small rural communities: 77% serve populations <1,000 e.p. and only a few serve large communities. The largest WSP system in France is in Rochefort sur Mer; it covers an area of 40 ha and serves a peak summer population of 50,000 e.p.

The performance of WSPs in France is generally good [11] (Table 2). Special attention is given to the technique and the parameters concerning the design of the ponds [12]. Practical expertise acquired during the last years has led to modifications in the design recommendations of the first facultative basin of WSP systems. Its active surface area is now 6 m^2/e.p. in order to limit the risk of malfunctioning. The cumulated surface of the second and third maturation basins is maintained at 5 m^2/e.p. (2.5 and 2.5 m^2/e.p.). They use a combined sewerage network. Another practical point is also that WSPs must receive mainly diluted influents. Globally, the plants are, on average, far from their nominal loadings, which explains why sludge's removal takes place on average every 14 years and the height of sludge accumulated is approximately 2.0 cm/year [13]. Furthermore, intermittent sand filters systems, with or without the plantation of reeds, have been adapted in order to improve the effluent's quality [10].

2.4. Italy

No recent data for an extended use of WSPs in Italy were found. A relatively recent study [14] mentions that in order to mitigate water stress in southern Italy, four feasible technological alternatives, among them WSP systems, have been tested in field scale at four sites (Cerignola, Ferrandina, Caltagirone, S. Michele di Ganzaria) to assess their effectiveness for producing reclaimed wastewater suitable to be used in agriculture. The main results recorded have been the following for the WSPs: TSS, BOD_5, COD, and nutrients concentrations achieved in the force Italian limits for wastewater agricultural reuse.

2.5. Spain

Spain shows a rising interest in the use of WSPs during the last decades. This comes out from the construction of new or the extension of preexistent systems as well as from the number of inquiring programs and studies that are carried out, concerning WSPs. Such a program takes place at the University of Leon (Northwest Spain), investigating the use of more complex forms of wastewater treatment systems, combining WSPs and Constructed Wetlands (CWs). Most of the WSPs in Spain are in the southeast of the country, especially in the provinces of Murcia, Alicante, and Almeria [15–17]. However, a great number of ponds also exist in Catalonia, in North Spain (Table 2). Catalonia has currently more than 200 urban wastewater treatment plants (WWTPs), but there are also numerous small WWTPs in rural population centers. Eight of those systems are WSPs [18,19], which are used in small rural communities (90–2,800 e.p).

2.6. Portugal

The WSPs are one of the most common wastewater treatment systems in Portugal [20,21]. By 1998, there were already 44 WSP systems in Portugal treating municipal wastewaters [22] and a further 20 treating piggery wastes [15,23]. The municipal WSP systems serve populations of 500–40,000 e.p. A typical system is that of Vidigueira in Alentejo, while over 50% of WSP systems are in the tourist area of the Algarve. The efficiency of BOD_5 removal is between 85 and 95% in the winter and 60% in the summer, due to the high consecrations of algae [24].

3. The systems efficiency

All of the aforementioned countries have similar climate, similar living standards, and social habits [2]. Nevertheless, differences do exist in WSPs' popularity, design and construction, operation and maintenance, and in the systems' efficiency. The prevailing combination of ponds used in every country is presented in Table 4. Many studies, concerning the efficiency of WSPs, are carried out in Europe. Depending on the country, the systems' efficiency, according to the literature references and our measurements, is presented in Table 5.

Table 4
Succession of ponds in the prevailing system of every country

Region	Succession of ponds in series
France	Anaerobic-facultative-2 maturation (French system)
Portugal	Anaerobic-facultative-2 maturation (French system)
Spain	Anaerobic or facultative-2 maturation
Italy	Facultative-2 maturation or French system
Greece	Older system: facultative-2 maturation, New system: French system
Cyprus	Aerated ponds

Table 5
Average removal efficiencies of WSP systems in Mediterranean Europe countries

Region	BO_5	COD	TSS	TKN	NH_4-N	TP	TC/100 ml	FC/100 ml
Greece	95.2	85.0	77.3	75.0	81.5	45.2	94.99	99.99
Cyprus	92.5	89.5	81.8	65.1	84.5	45.1	N.D	N.D
France	91.7	84.9	76.6	68.6	70.8	59.5	N.D	N.D
Spain	70.1	N.D	61.5	67.0	N.D	52.0	N.D	99.80
Portugal	80.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D

N.D: Not determined.

The methodology for siting areas for WSPs is quite complicated. It is based on a selection process that takes into account both environmental and design criteria, topography, land use, type of geological formation, distance to major rivers or lakes, distance to existing cities and villages, mean minimum monthly temperatures, the existence of environmentally protected areas, population served, and required wastewater effluent characteristics. For this reason, Geographic Information System can be a useful tool to sit areas for WSPs' construction [25]. Moreover, it is noticeable that a proper way to construct a WSP needs to take into account the various design modifications (construction materials, insulation, installation of heat exchanger, etc.) [26]. A Computational Fluid Dynamics Model can be used for that reason, so as to assess the impact of different pond design scenarios [26].

Another issue, relative to the use of WSPs, is high land area requirements. The most feasible solutions to this problem are effluent recirculation from the last to the first pond of WSP system or step-feeding. Recirculation is an attractive option, as it enhances ponds' efficiency, decreases land area requirements, and prevents the formation of undesirable odors. This way, three times more wastewater can be treated in the same pond area than with a WSP system without recirculation [27].

Furthermore, various studies have been conducted concerning the factors affecting the inactivation of bacteria and pathogenic parasites in WSPs. Such factors are the sunlight (solar radiation), the plants (algal concentration), the depth, the temperature, the seasonal variations as well as pH, the dissolved oxygen (DO), and humic substances [28–31]. At the University of Leon (northwestern Spain), a study concerning mechanisms for parasites removal (i.e. faecal bacteria) was carried out [28,29], proving that anaerobic ponds are effective in removing parasites, when followed by a facultative and a maturation pond.

Other studies have been occupied with the heavy metals' concentrations in the WSPs' effluents. The bioavailability and toxicity of heavy metals, coming from WSPs' sludge, was proved to be below maximum permitted levels [32]. The WSPs are effective even in the case of piggery wastewaters, which contain high concentrations of nitrogen, phosphorus, and organic matter. However, we are still far from the target discharge limits established for protected areas [33].

Algal ponds present one of the most popular treatment methods; however, they produce a significant amount of algal biomass which is difficult to manage, when a high-quality effluent is required (e.g. in the case of strict standards) [27,34]. Moreover, they cause problems in irrigation infrastructure networks (in the low-flow drip-irrigation systems) [35]. For that reason, several inquiries are searching for alternative methods so as to replace the algae-based systems with other systems, such as macrophyte-based ones. Moreover, they are studying the prospect of combining WSP and CW systems for the treatment of algae-pond effluents [36–38]. Concerning this issue, extended research has also been done in the use of duckweed treatment systems. Duckweed is a kind of plant surviving in extreme temperatures and forming a leaf canopy on the water's surface. This fact results in the suppression of the algae growth, leads to anoxic and neutral conditions in the pond system, and reduces odor release. However, the duckweed needs to be routinely harvested manually or mechanically, so that it gets effective [34,39].

4. Treated wastewater reuse

The Mediterranean region is characterized by common issues related to environmental and development problems, concerning water resources management, their development and pollution control [40]. However, there are differences in the legislation regarding the reuse of ponds' effluents, the mentality with regards to wastewater treatment, and reuse and the needs [41].

In Greece, despite adequate precipitation, water imbalance is often experienced, due to temporal and regional variations of precipitation, the increased water demand during the summer, and the difficulty of transporting water due to the mountainous terrain. The only guidelines/criteria for wastewater reclamation and reuse have been set at 2008 (Government Newspaper FEK. 2089/issue B/9-10-2008) and demand as a minimum coagulation, filtration and disinfection, with a filtration speed less than $8\,m^3/m^2/h$, followed by secondary treatment. Quality demands are: $BOD_5 < 10$ mg/L, SS < 10 mg/L, and *T. colliforms* 2/100 ml for 90% of the samples. Additionally, *T. Colliforms* should not exceed 20 per 100 ml in more than one sample for a full two-month period. Sampling should take place at least once every three days; for remote areas, it is once every 7 days. No limitation is applied regarding the irrigation method of choice. Quality demands are rather strict and license for effluents' reuse for irrigation is time-consuming and difficult to obtain. Therefore, only a few small projects on wastewater reclamation and reuse are in place. Still, despite the strict guidelines, it is quite common for farmers—especially during the summer months—to use water from unguarded and abandoned WSPs (that operate without permit), in order to irrigate industrial plants crops or fodder crops.

The criteria for wastewater reuse are equally strict in Cyprus. BOD_5, SS, and FC effluent concentrations for unlimited irrigation should not exceed 10 mg/L, 10 mg/L, and 5–15/100 ml, respectively. Recycled domestic water is used for the watering of football fields, parks, hotel gardens, etc. (1.5 million m^3/yr) and for the irrigation of permanent crops in particular (3.5 million m^3/yr). It is estimated that by 2012, an amount of approximately 30 million m^3/yr of treated sewage effluent will be available for agriculture and landscape irrigation [9]. The Quality Guidelines in Cyprus are based on two different approaches (WHO proposals and California State Regulations) in tune with local conditions. The use of WSPs is permitted on the condition that the total detention time in the maturation ponds exceeds 30 days and that the number of FC does not exceed 1,000 per 100 ml for fodder crops and 3,000 per 100 ml for industrial crops.

Wastewater reuse is not very common in France, as most of the needs are fulfilled by water resources. Since 1996, over 2,000 ha of vegetables near Paris and 600 ha near Reims are irrigated with treated wastewater. The crops grown are alfalfa, maize, sugar, beet, peas, and sunflower [42]. Treated wastewater is also used for landscape and golf courses irrigation in some tourist areas of South France. Generally, French legislation imposes the study of the possibilities and criteria for wastewater reuse for each case separately. The legislation does not define definite criteria for metals or organic compounds in wastewater; the relevant bureau asks a panel of experts to decide whether or not to reuse the treated wastewater.

In Italy, wastewater storage and reuse for agricultural purposes has become more popular as a practice in many rural communities of Sicily (e.g. Grammichele and Caltagirone). The use of wastewater in Italy is regulated by the 12/6/2003 legislative set of rules. The Italian standards follow a quite strict approach, especially for some chemical compounds; in many cases, the quality standards for reclaimed wastewater are the same as for drinking water [43]. The guidelines for BOD_5, SS, and T.C. are the same as in Greece.

In Spain, interest arises concerning sludge suitability for agricultural application [44]. A National Hydrological Plan, which has recently been published, is favorable to the reuse of treated wastewater for irrigation. In any case, the reuse of treated wastewater is already a reality in several Spanish regions for different applications: golf course irrigation, agricultural irrigation, groundwater recharge (in particular, to stop saltwater intrusion in coastal aquifers), and river flow augmentation. Commercial interest exists and some private water companies invest in Research and Development activities, in collaboration with the Universities. The guidelines for wastewater reuse are: for unlimited irrigation F.C < 10/100 ml, for limited irrigation F.C < 200/100 ml, and for the irrigation of grazing grounds F.C < 500/100 ml [45].

In Portugal, treated wastewater is a valuable potential resource for irrigation [46] and contributes to the agricultural development in the driest Portuguese provinces (i.e. Beja, Evora, Setubal, Lisboa, and Santarem). They irrigate approximately 35,000–100,000 ha, depending on storage capacity. Interest is also growing on the irrigation of golf courses [45].

5. Conclusions

The WSPs have been widely used in Mediterranean Europe, in countries like Spain, Portugal, and France for the last 25 years. In Greece, their use is becoming more popular lately, especially in small rural settlements due to their low cost, simplicity, and reliability. In all countries, the systems treat wastewater from combined sewer systems. The systems in Greece strangely exhibited higher pollutants removal compared to systems from other countries, despite their less than perfect design and their nonexistent maintenance. Still, the treated effluents do not meet the reuse standards, which differ from country to country. Italy and Greece have set the strictest standards for reuse. Cyprus sets different standards based on the use. Special attention should be given to the subject of quality; as wastewater reuse is becoming increasingly necessary in the Mediterranean countries, where the financial and social development is associated with agricultural and touristic activities.

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