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Small wastewater systems in Portugal: Current situation and trends for the future

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ABSTRACT

Portugal is a small Mediterranean country. Where wastewater treatment is concerned, the Portuguese levels of service in 2000 and 2006 were, respectively, 55% and 80%.These levels of service will continue to increase until 2013. Because of economic, environmental, and energy concerns, the design, construction, and operation of wastewater treatment plants (WWTPs) are currently under careful review in Portugal. Innovative designs continue to be developed and alternative treatment processes, specifically those based on natural systems, such as constructed wetlands, are being used. This paper presents information about investment costs of 165 wastewater treatment plants (WWTPs) built in Portugal between 2002 and 2004. The WWTPs were grouped in four population ranges that were analysed in terms of investment per capita costs. For the lowest range, up to 2000 inhabitants, the average investment cost was about €800 per inhabitant and just €89 per inhabitant for WWTPs serving more than 30,000 inhabitants. The analysis of investments related to WWTPs serving fewer than 2000 inhabitants has shown a large variation of unit costs, depending on the served population and, to a much smaller extent, on the type of wastewater treatment. In this paper, special attention is also given to three main groups of sustainability indicators, comparing conventional treatment systems with constructed wetlands. Results show benefits of selecting wastewater treatment based on natural systems.

Keywords: Constructed wetlands; Investment costs; Levels of service; Wastewater treatment

1. Introduction

Until 1993, wastewater service in Portugal was directly and exclusively the responsibility of local councils. Generally, investments were made in finding solutions to local problems without seeking integrated solutions for several municipalities which might have improved service quality and profitability; there was no concern for synergies and scale economics [2]. This trend resulted, sometimes, in a lack of infrastructures, low servicing levels and wrongly-focussed investment.

With the publication of Decree Law no. 379/93, wastewater service became open to the private sector and conditions to develop plurimunicipal systems were established. The legal framework now in place is essentially based on the following models:

- Municipal systems, where municipalities are directly involved in system design, construction and management, or indirectly though the creation of municipal companies,
- Plurimunicipal systems (intermunicipal or multimunicipal systems). In intermunicipal systems, the design, construction and management of infrastructures are ensured by a partnership of municipalities,

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with or without private participation. In multimunicipal systems the design, construction and management of infrastructures are ensured either directly by the state or by means of a concession contract with a regional company created exclusively for this purpose.

Nowadays, about 79% of the 278 Portuguese mainland municipalities are integrated in plurimunicipal wastewater systems, corresponding to about 70% of the total served population. 80% of the plurimunicipal systems are multimunicipal, just 20% being intermunicipal.

During the period 2000–2006, about €2450 million was invested in water supply and collection and treatment of wastewater [1]. During the period 2007–2013, an additional investment of more than €3500 million has been planned for these purposes. A significant part of this additional investment will be applied to the construction and up-grading of small wastewater treatment systems, the main challenges being to develop, taking into account this background, sustainable solutions in economical, environmental and social terms.

In fact, in late 2007, the Ministry of Environmental, Territorial Planning and Regional Development (MAOTDR) approved PEAASAR II — the strategic plan for water supply and collection and treatment of wastewater for the period 2007–2013. PEAASAR II established the following three strategic objectives: 1) universality, continuity and quality of service; 2) sustainability of the sector and 3) protection of environmental values.

The main operational objectives of PEAASAR II regarding wastewater systems are: a) to serve approximately 90% of the Portuguese population, each individual integrated system having to serve at least 70% of the population of the tributary area; b) to ensure the recovery of the investment and operational costs; c) to contribute to the development and dynamics of national private enterprises and d) to fulfil objectives of environmental protection and public health.

In PEAASAR II strategic orientations are developed for integrated management of urban water, including efficient water use and best practices for wastewater management, using for example, eco-efficient energy solutions. In PEAASAR II the pricing of the service assumes a relevant importance, as do the sustainability of the systems and the integration of upstream sewer networks and downstream infrastructures: interceptors and Wastewater Treatment Plants (WWTP).

In the past, interest in small treatment systems has often been overshadowed by concern over the design, construction, and operation of large regional systems. Small systems were often designed and constructed as small-scale models of large plants. As a consequence, many are operationally energy- and resource-intensive. Because of economic, environmental, and energy concerns, the design, construction, and operation of small systems are currently under careful review in Portugal. New and innovative designs continue to be developed and alternative treatment processes, specifically those based on natural systems, such as wetlands, are being used.

In this paper, a special emphasis is given to small wastewater treatment systems, in particular to per capita investment costs and sustainability indicators.

2. Current situation

As far as wastewater treatment is concerned, the Portuguese levels of service in 2000 and 2006, were, respectively 55% and 80%. Fig. 1 shows the geographical distribution of wastewater levels of service in Portugal in 2000.

The initiative to construct wastewater infrastructures in the last decade has resulted in 1035 new wastewater treatment plants, 1127 pumping stations and 4067 km of trunk sewers. For serving agglomerations with fewer than 2000 inhabitants, 348 new WWTPs have been constructed and 128 existing WWTPs rehabilitated.

Despite the progress resulting from the implementation of the first strategic plan for water supply and collection and treatment of wastewater for the period 2000–2006 – PEAASAR I [4], there are still structural, operational and environmental problems in the sector, mainly related to small wastewater networks of municipal systems.

The significant number of small decentralised systems which cannot benefit from economics of scale and the lack of specialized human resources to support the efficient management and operation of infrastructures are the main causes of the present difficulties. Additionally, there are still cases of non-compliance with European and national legislation regarding wastewater discharges into the receiving waters.

In the natural environment, physical, chemical and biological processes occur when water, soil, plants, microorganisms, and the atmosphere interact. Natural treatment systems are designed to take advantages of these processes to provide wastewater treatment. The processes involved in natural systems, such as constructed wetlands, include many of those used in mechanical or in-plant treatment systems, plus others unique to natural systems such as photosynthesis, photooxidation, and plant uptake.

In Portugal, a significant trend over the past 10 years has been the construction of wetlands for serving small agglomerations, mainly subsurface horizontal flow constructed wetlands. In a sample of 112 WWTPs constructed in Portugal between 2002 and 2006, serving fewer than 2000 inhabitants, 79% were constructed wetlands, the remaining mostly being activated sludge plants (extended aeration and oxidation ditches).

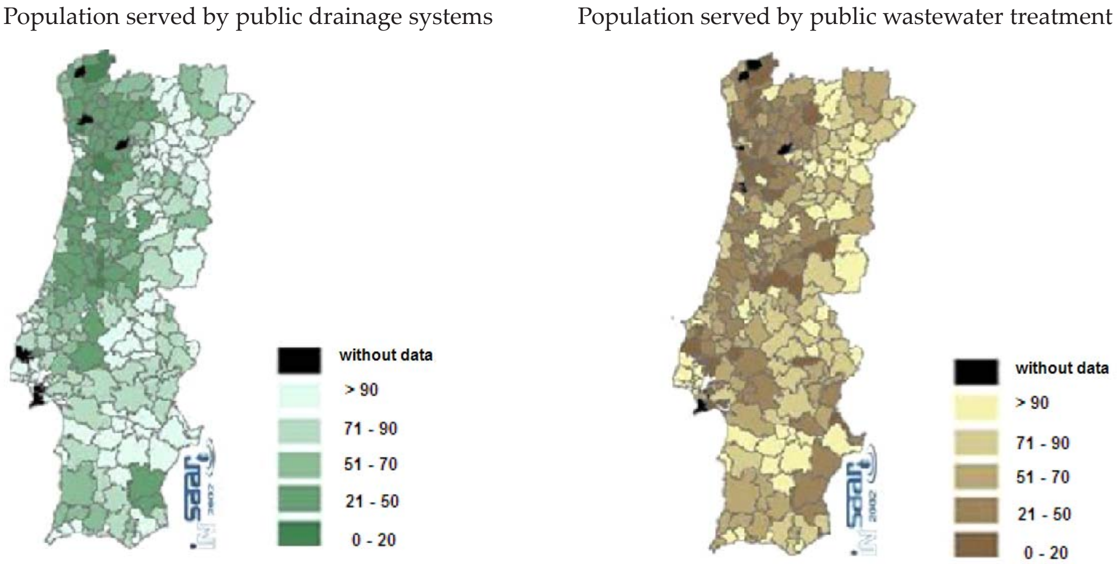

Fig. 1. Geographical distribution of wastewater levels of service in Portugal in 2000 (adapted from INSAAR [3]).

3. Wastewater treatment plant investment costs

The investment costs of a group of 165 WWTPs built in Portugal between 2002 and 2006 were analyzed, these costs including civil works and equipment. Selected are part of ten multimunicipal systems operating in Portugal, and serve a total population of about 1.6 million inhabitants. Fig. 2 shows: a) the number of WWTPs grouped by served population and b) the total served population in each group. The WWTPs were grouped according to the following ranges:

- Group 1 – WWTPs with served populations of more than 30000 inhabitants;
- Group 2 – WWTPs with served populations of between 10000 and 30000 inhabitants;
- Group 3 – WWTPs with served populations of between 2000 and 10000 inhabitants and
- Group 4 – WWTPs with served populations of less than 2000 inhabitants.

The main technology selected for larger plants is based on activated sludge. In fact, the 12 plants serving more than 30 000 inhabitants (Group 1) are conventional activated-sludge aeration or oxidation ditches. For Group 2, 50% of the WWTPs are extended aeration plants, with the other 50% being oxidation ditches. For Group 3, 13% of the 31 WWTPs are trickling filters, 35% are extended aeration systems and 52% are oxidation ditches. In Group 4, WWTPs serving smaller agglomerations, 88 of the 112 WWTPs are constructed wetlands, 1 is a lagoon system, 2 are trickling filters and the remaining 19 are activated sludge plants with extended aeration or oxidation ditches.

It can be seen that 78% of the total served population is allocated to only 7% of the WWTPs (Group 1), while 4% of the population is served by 68% of the WWTPs (Group 4). This situation is reflected in terms of per capita costs, as presented in Table 1.

The investment costs associated with the construction of WWTPs are closely related to the corresponding served population, showing the economics of scale of large systems, compared with smaller ones.

As expected, the average cost per inhabitant (inh) is much lower in Group 1 (€89/inh) and higher in Group 4 (€812/inh), which reflects the magnitude of the econom-

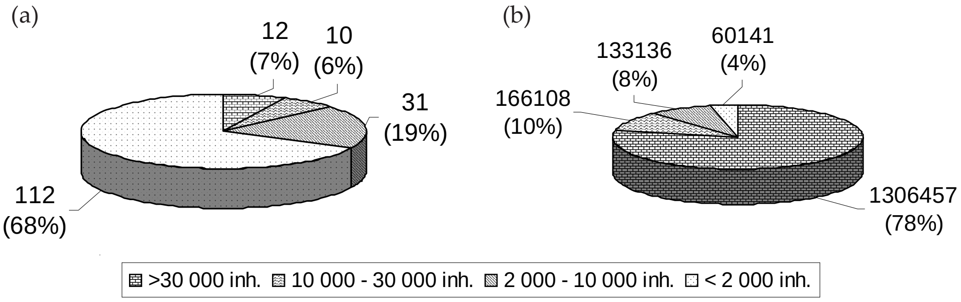

Fig. 2. (a) Number of WWTPs grouped by served population, (b) Total served population by each group.

Table 1
Average WWTP investment costs per capita, for each population range

Population range	Nº WWTP	Investment cost per capita (€/inh.)
1. >30 000 inh.	12	89
2. 10 000–30 000 inh.	10	123
3. 2 000–10 000 inh.	31	183
4. <2 000 inh.	112	812

ics of scale of the investments. The analysis of the information concerning WWTPs serving fewer than 2000 inhabitants show a large variation of unit costs, depending on the served population and, to a much smaller extent, on the type of wastewater treatment, as can be seen in Fig. 3. Per capita costs, in this range, vary between €200 and €3000, with activated sludge plants (extended aeration and oxidation ditches) presenting slightly higher values. The economics of scale is especially significant in terms of per capita costs in the range of 50–500 inhabitants.

4. Sustainability indicators

4.1. General aspects

According to the Brundtlard Report, sustainable development is defined as the "development that satisfies the needs of the present, without compromising the future generations' abilities of satisfying their own needs"; WWTPs complying with the same standards for effluent quality, but with lower installed power, lower energy needs, lower amounts of concrete used and lower operation and maintenance costs, should be considered, in those aspects, more sustainable. On the other hand, an important aspect when analysing sustainable development may be monitoring sustainablility indicators, an indicator being "a parameter or a value derived from parameter, which points to, provides information about, describes the state of a phenomenon environment area, with a significance beyond that directly associated with a parameter value" [6]. Indicators are measuring instruments and their application must be defined and structured in order to be a useful tool.

Sustainability indicators for wastewater treatment can be divided in three main domains: environmental, economical and social. Examples of environmental sustainability indicators are: installed power per inhabitant (kw/inh), annual energy consumption per inhabitant (kwh/inh/year) and used concrete per inhabitant (m^3/inh**)**. The comparison of these specific aspects of the different types of wastewater treatment can contribute to a better understanding of their benefits and advantages (and disadvantages) thus supporting decisions concerning choices for restoration or construction of WWTPs.

4.2. Environmental indicators

Galvão et al. [7] analysed twenty one secondary WWTPs operating in Portugal, serving populations of fewer than 2300 inhabitants. All these WWTPs have been designed to reach a similar objective in terms of the effluent Biochemical Oxygen Demand (BOD_5 ≤25 mg O_2/l) and total suspended solids (TSS ≤35 mg/l).

Fig. 4a shows the relationship between served population and amount of concrete used in civil works. The amount of concrete refers to the total infrastructures and components related to treatment, such as channels, pumping installations, septic tanks and Imhoff tanks in addition to the biological reactors. Fig. 4b shows the relationship between served population and installed power per inhabitant, for conventional systems (trick-

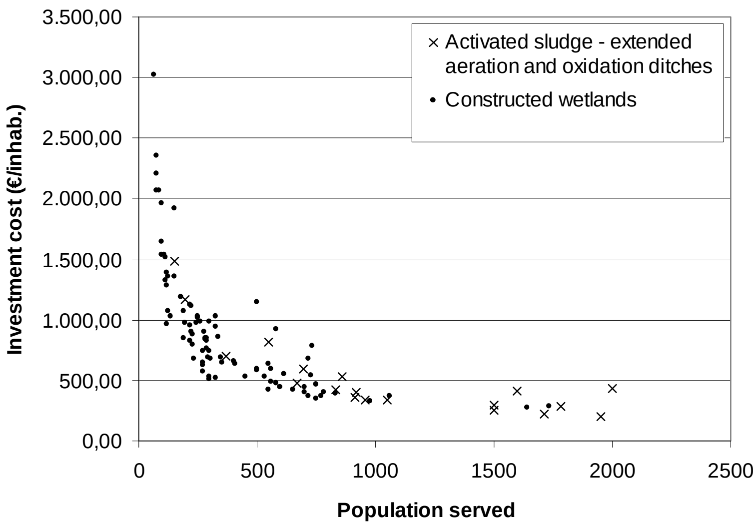

Fig. 3. Investment per capita costs for subsurface horizontal flow constructed wetlands and activated-sludge plants.

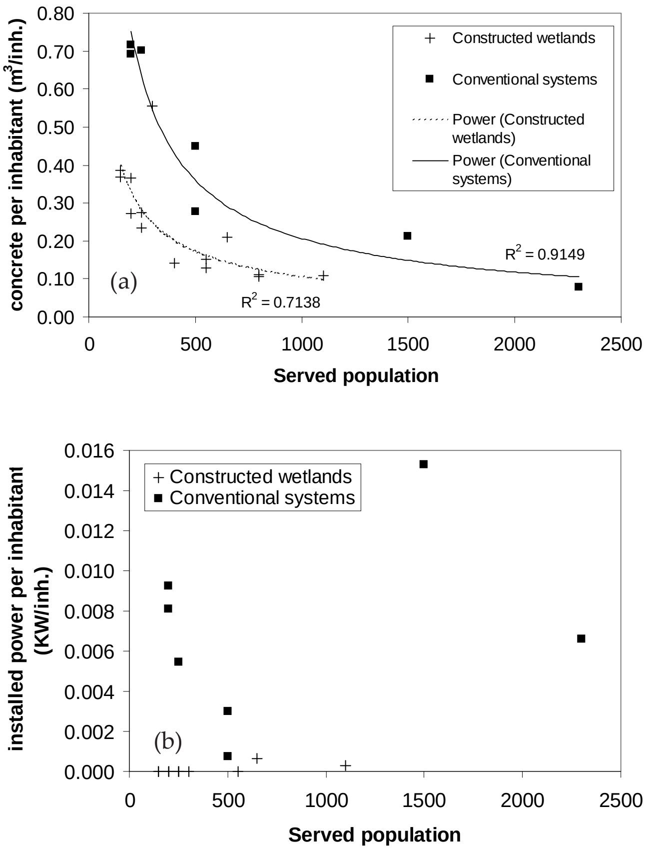

Fig. 4. (a) Relation between served population and amount of concrete used per inhabitant; (b) Relation between served population and the installed power per inhabitant.

ling filters and activated sludge extended aeration or activated sludge oxidation ditch plants) and for subsurface horizontal flow constructed wetlands.

From the data presented in Fig. 4a it is clear that the amount of concrete used in conventional WWTPs is higher (in general 2–3 times higher) than in constructed wetlands systems, for the same served population. As can be seen from Fig. 4b it is likely that many constructed wetlands do not need electromechanical equipment in order to be operational. In the case of smaller constructed wetland systems, it is common to store the sludge in septic tanks, installed upstream from the wetland beds.

Based on data collected from the same WWTPs, Espadinha et al. [8] compared the percentage of energy consumed in WWTPs operating in Portugal with the total energy consumed by the served populations. It was shown that in small WWTPs conventional systems (trickling filters and extended aeration plants, for example), the percentage of energy consumed with wastewater treatment, on an annual basis, varies from 1.5 to 4% of the total energy consumed by the population, depending on the type of treatment and on the specific characteristics of the site, whereas in sub-surface horizontal flow constructed wetlands, the percentage of energy consumed varies from 0 to 1.5%.

5. Trends for the future

The Portuguese Government has set the goal of a 90% level of service regarding wastewater systems, to be achieved by 2013. This will require the construction of both WWTPs and sewer systems. A significant part of the planned investment will be applied to the construction and up-grading of small wastewater systems, the main challenges being to develop, against this background, sustainable solutions in economical, environmental and social terms.

Since WWTPs for small agglomerations are usually small in size, not much attention seems to be paid to their operation and maintenance. That situation may be especially problematic if the selected technology requires specialised human resources.

It is believed that, in ten years' time, the majority of the wastewater infrastructures will have already been built and will be in operation. The main challenges will be related to asset management, namely to energy and nutrient recovery (eco-efficiency) and effluent reuse. In this scenario, constructed wetlands seem to be a sustainable alternative for the wastewater treatment of small agglomerations since they can be designed, in many situations, to rely almost entirely on natural processes and gravity flow. The maintenance work required is also considerably less than with conventional systems.

In the great majority of developed countries, the construction of water pollution control facilities has generally favoured "concrete and steel" alternatives. With the higher energy prices and higher labour costs, these systems have become significant cost items with the result that processes that use relatively more land but are lower in energy use and labour costs are becoming more and more attractive for the management authorities. In addition, the maintenance required is considerably less than with a conventional system, and the entire treatment system often has the ability to operate for long periods with no human intervention whatsoever. These characteristics generally place constructed wetlands in the sustainable approach category, particularly due to their ability to provide multiple function and benefits at low cost and with low environmental impact.

In fact, more than one hundred constructed wetlands have been put into operation in Portugal during the last 10 years. This technology has acceptable per capita investment costs when compared with alternative treatment solutions. In addition adequate sustainability indicators may support the choice of this more natural solution for treating effluents from small agglomerations.

Aspects such as flow reduction along the wetland beds due to evapotranspiration, which sometimes leads to "zero discharge" for part of the day, during summer, or the microorganism removal along the wetlands are now being considered especially important in Portugal. The relevance of these aspects arise from the typical characteristics of the receiving waters in Mediterranean countries, in general small brooks with very low flows during dry period, often discharging to sensitive zones. The potential for effluent reuse for agriculture purposes may also be relevant in respect of requirements for effluent quality. However, it is believed that further intensive research is needed in these areas in the near future.

6. Final considerations

The experience gathered in Portugal since 1995 and the need for the best use of European funds in the period 2007–2013 has lead the Ministry of Environment, Territorial Planning and Regional Development to develop strategic guidelines for water supply and wastewater collection and treatment. The sustainability of the sector, including the recovery of the investment and operational costs and the protection of environmental values, have deserved special attention.

Decentralized systems for treating wastewater from small agglomerations with constructed wetlands can provide not only a more economical and energy-efficient way of achieving treatment objectives, but also a resource in the form of reclaimed water available for landscape irrigation or creation of wildlife habitats. In Portugal, more than 300 small WWTPs have been constructed during the last eight year period. In this paper, the investment costs of 165 WWTPs are presented, 112 of these WWTPs serving fewer than 2000 inhabitants. The average investment cost (including civil works and equipment) of the smaller WWTPs is about €800 per inhabitant. In this range, constructed wetlands and activated sludge extended aeration plants present similar investment costs. In Portugal, the recent trend for the construction of subsurface horizontal flow constructed wetlands for wastewater treatment of small agglomerations results, principally, from the low operational costs and low consumption of resources. The consumptions of resources may be expressed as environmental sustainability indicators, enabling the comparison of different schemes and types of treatments, in different aspects. Some results concerning environmental sustainability indicators have been presented in this paper, showing the benefits of wastewater treatment based on natural systems.

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References

[1] Ministério do Ambiente, Ordenamento do Território e Desenvolvimento Regional, Plano Estratégico de Abastecimento de Água e de Saneamento de Águas Residuais (2007–2013) – PEAASAR II, Lisbon, Portugal, 2007.

[2] J. Matos, S. Santos, S. Dias and F. Ferreira, Small wastewater systems in Portugal – Challenges, strategies and trends for the future, International Conference on Small Wastewater Technologies and Management for the Mediterranean Area, Sevilha, Spain, 2002, pp. 169–190.

[3] INSAAR, Inventário Nacional de Sistemas de Abastecimento de Água e de Águas Residuais, http://insaar.inag.pt/index2_noflash.htm, 2002.

[4] Ministério do Ambiente e Ordenamento do Território, Plano Estratégico de Abastecimento de Água e de Saneamento de Águas Residuais (2000–2006) — PEAASAR, Ministério do Ambiente e do Ordenamento do Território, Lisbon, Portugal, 2000.

[5] Metclaf & Eddy, Wastewater Engineering: Treatment Disposal and Reuse, 3rd ed., McGraw Hill, New York, 1991.

[6] Organização para a Cooperação e Desenvolvimento Económico — OCDE, Environmental Indicators — Development, Measurement and Use, 2003.

[7] A. Galvão and J. Matos, Sustainable sewerage solutions for small agglomerations, Water Sci. Technol., 52(12) (2005) 25–32.

[8] C. Espadinha, A. Marcão, A. Fábregas, A. Galvão and J. Matos, Sustainable indicators of treatment solutions for small agglomerations, International Meeting on Phytodepuration, Lorca, Murcia, Spain, 2005.