Characteristics and performance of small and medium wastewater treatment plants in Greece

E. Gavalakis*, P. Poulou** and A. Tzimas*

* EMVIS Consultant Engineers SA, 21 Paparrigopoulou Str., Agia Paraskevi, 153 43, Athens, Greece
(E-mail: *egavalakis@emvis.gr)*
** Ministry of Environment and Energy/Special Secretariat for Water, 17 Amaliados Str., 115 26, Athens, Greece
(E-mail: *p.poulou@prv.ypeka.gr*)

Abstract
Wastewater management in Greece is being regulated by the Urban Waste Water Treatment Directive (UWWTD). Many WWTPs were constructed during the last 30 years and the current challenge lies on the efficient operation of these works along with the need to fulfil the obligations set in the Directive with projects that are related to areas with p.e. less than 10.000. The present work aims to outline the progress regarding the implementation of the UWWTD, present deficiencies and future challenges. An evaluation of the WWTPs performance is conducted for small-medium and large WWTPs focusing to the quality characteristics of the effluent, whereas additional information regarding wastewater influent characteristics is presented. All data used were obtained from the data uploaded to the National Database for the collection and storage monitoring data from the WWTPs in Greece operated by the Special Secretariat for Water of the Ministry of Environment and Energy.

Keywords
Wastewater treatment plants, performance indicators, Greece, UWWTD

WASTEWATER MANAGEMENT IN GREECE

Legal basis Implementation of 91/271/EEC Directive Reporting obligations

Wastewater management in Greece is being regulated by the Urban Waste Water Treatment Directive (UWWTD) which has been established in 1991 by the European Commission, in an effort to identify minimum requirements for collection and treatment of urban wastewater. The relevant document is one of the key policy instruments under the EU water *acquis* and its implementation since its adoption in 1991 has, in particular, significantly reduced discharges of major pollutants such as organic load and nutrients, main drivers for eutrophication in waters (EC, 2016).

Implementation has been challenging due to financial and planning aspects linked to the construction of wastewater infrastructure. Over the years and to help meet these challenges, the EU dedicated a significant amount of funding under the EU Cohesion Policy funds (appox. 17.8 billion EUR in the 2007-2013 programming period at an EU level). Investments in infrastructure have, directly and indirectly, a positive impact to economic growth and employment and therefore contribute to one of the key priorities of the current Commission to boost jobs, growth and investment (EC, 2016).

In Greece the UWWTD was incorporated to the national legal framework in 1997 (Ministerial Decree 4673/400/1997), with amendments in 1998, 1999 and 2002, which were mainly related to the identification of sensitive areas. The peak for the implementation of the UWWTD in Greece was the two decades from 1990 to 2010, when major projects were designed and constructed, mainly for medium and large agglomerations and to a lesser extend for smaller communities although it is acknowledged that several works that would serve smaller agglomerations (<10.000 p.e.) are still pending, the main constraint being the availability of adequate funding.

Although the UWWTD practically sets the obligations for agglomerations with population

equivalent (p.e.) exceeding 2000, it has been recognised as the baseline regarding desirable level of treatment depending on the type of recipient and indirectly its quality status for even smaller communities. In order to meet the need for sustainable wastewater management in small communities, the Special Secretariat for Water of Greece, published in 2012 a guidance document to determine appropriate systems and development criteria selection for processing sewage settlements form small agglomerations (i.e. <2000 p.e.). The document is addressed to water utilities and municipalities who wish to proceed to the construction of decentralised wastewater treatment systems.

Agglomerations

The understanding of the UWWTD presupposes the comprehension of several terms which mainly are related to the definition of the administrative unit for the implementation of the UWWTD, the level of treatment, the type and environmental status of the recipient. These criteria are used in the order to establish the strategic planning of wastewater infrastructure construction.

One of the most important definitions is related to the term "agglomeration", which means an area where the population and/or economic activities are sufficiently concentrated for urban waste water to be collected and conducted to an urban waste water treatment plant or to a final discharge point. In Greece 457 agglomerations are identified corresponding to 11.8 million p.e. in total, with their contribution among agglomeration classes being presented in Figure 1. It is evident that although the number of agglomerations for medium (5000-10000 p.e.) and smaller (2000-5000 p.e.) sized populations is high adding up to 337 agglomerations (almost 75% of the total number), the load produced does not exceed 20%. Although the contribution in terms of pollution load seems less significant, it should be stressed that the impact of point source pollution is related to the magnitude and the assimilative capacity of the recipient.

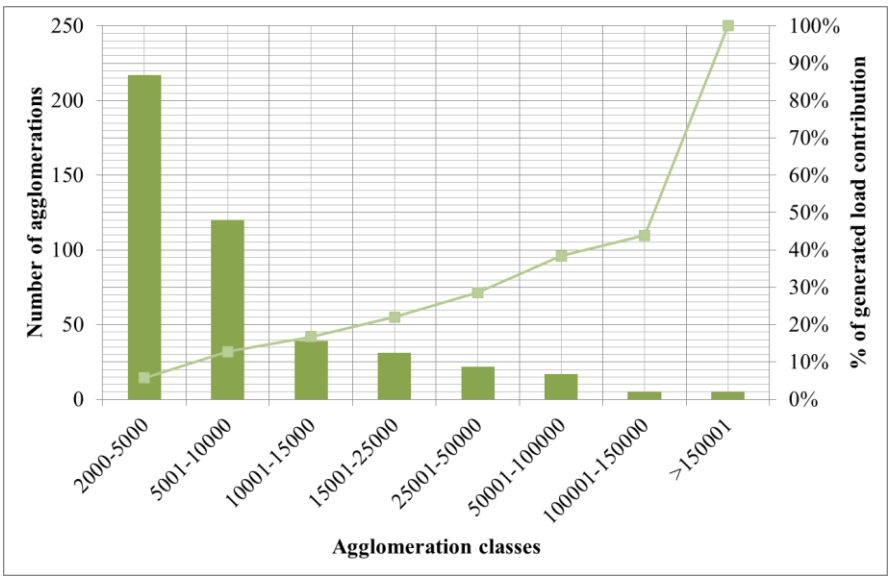


Figure 1. Number of agglomerations per agglomeration size class and percentage of generated load contribution

Population served

From the total number of agglomerations approximately 50% is served by a wastewater treatment plant, whereas considering that in practice one wastewater treatment plant may serve more than one agglomerations in the same area, the number of wastewater treatment plants that have been constructed and are operational is 205. The number of agglomerations that are served by wastewater treatment plants and respective classes is presented in Figure 2. From Figure 2 it becomes evident

that large cities and agglomerations with more than 25.000 p.e. have practically complied with the UWWTD since a small percentage of agglomerations is not connected which is related to areas in the south-east Attica Region, while the estimated generated load corresponds to the not negligible 110.000 p.e..

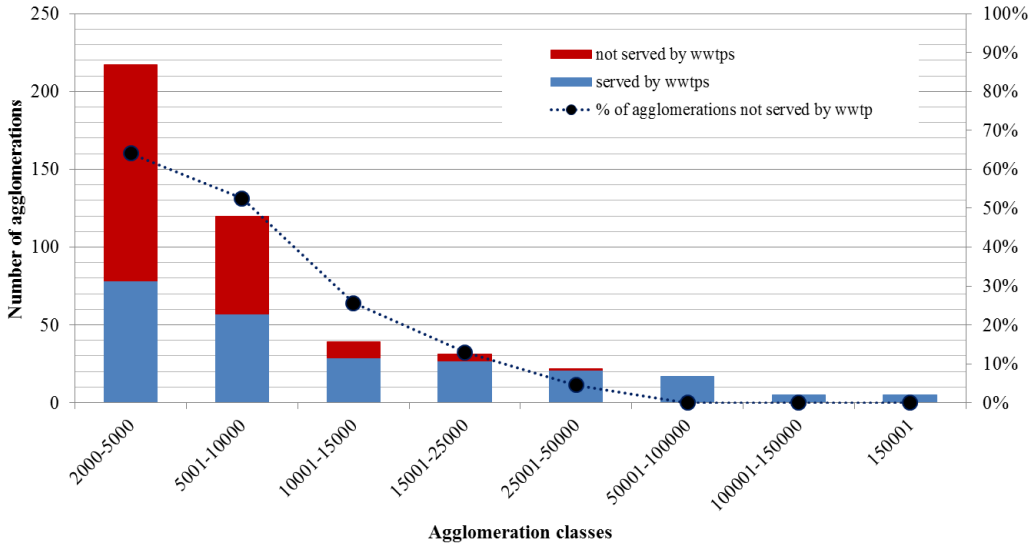


Figure 2. Number of agglomerations served by wastewater treatment plants and percentage not served per agglomeration class

As the agglomerations class become smaller, the percentage of areas that are not served by wastewater treatment plants significantly increases reaching 65% for agglomerations with population below 5000 p.e. with generating load corresponding to 420.000 p.e. (Figure 3).

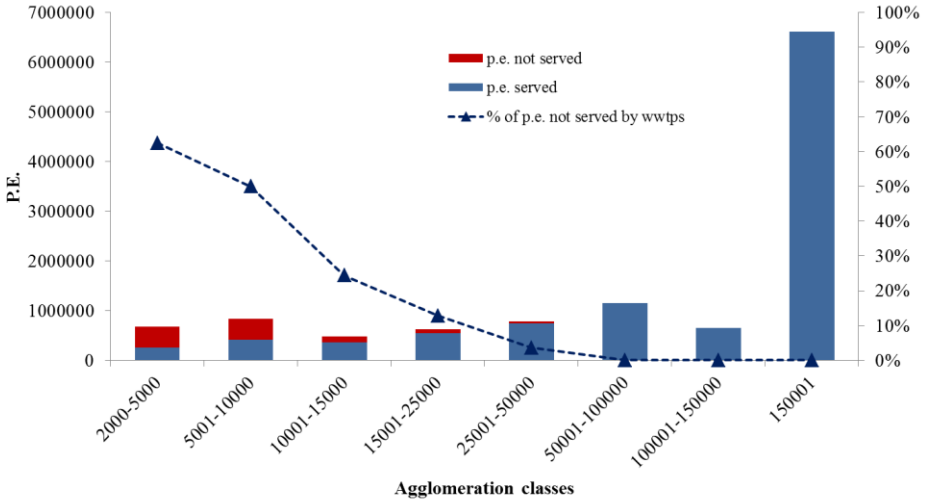


Figure 3. P.E. served by wastewater treatment plants and percentage not served per agglomeration class

Recipients

According to the UWWTD there are three types of receiving areas: normal, sensitive and less sensitive with this differentiation being related to the quality status of the recipient and the treatment requirements prior to disposal. In Greece most receiving waters are considered as normal (i.e. not subjected to eutrophication) while 12% of the agglomerations (30 agglomerations) are in vicinity to sensitive areas (Figure 3) and the relevant wastewater treatment plants are designed for nitrogen and/or phosphorus removal.

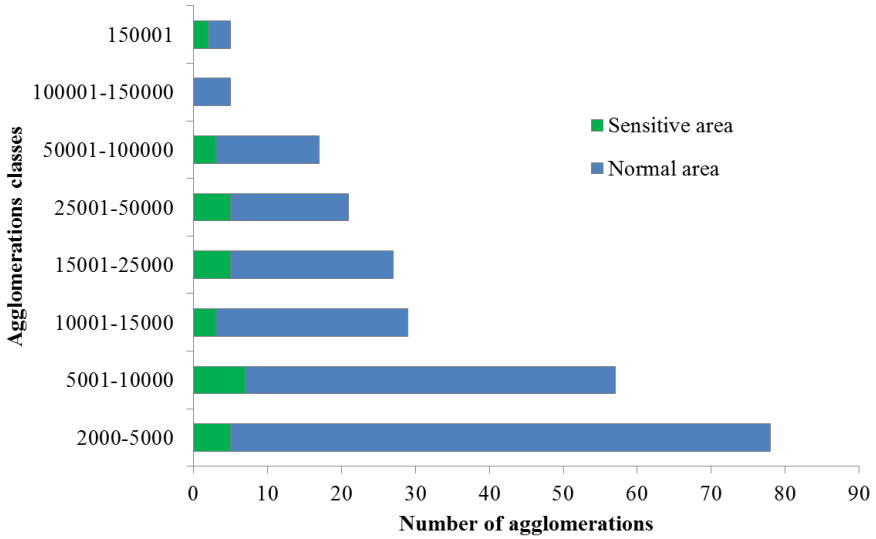
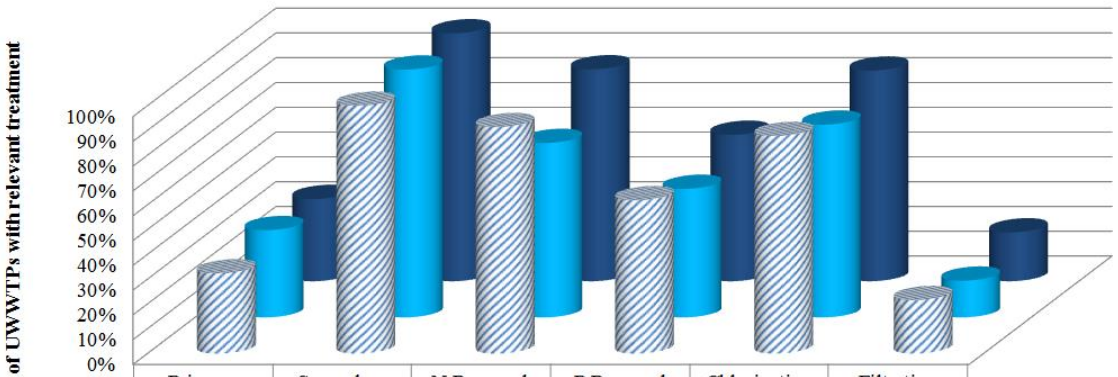


Figure 4. Number of agglomerations related to normal or sensitive areas for wastewater discharge

Treatment provided

In Greece the existing level of treatment provided is related to secondary treatment for the removal of organic load, which in most cases is supplemented by nitrogen removal (for more than 85% of the WWTPs) and/or phosphorus removal (60%). From Figure 5 it is evident that similar practices are used for small and larger wastewater treatment plants that involve biological treatment with nitrogen removal, with chlorination as the preference method for disinfection. Tertiary treatment including filtration is not widely practiced, which is expected considering the low percentage of wastewater reuse applications (only in 28 UWWTPs wastewater effluent is adequately treated for reuse applications corresponding to less than 2% of the total wastewater produced).



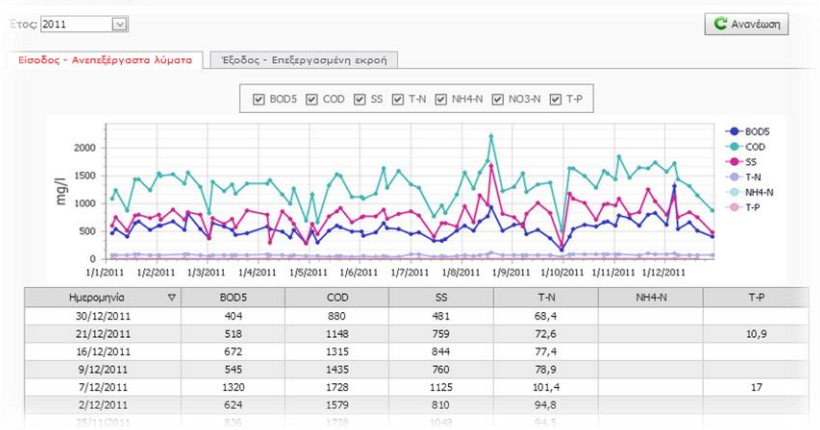
	Primary Treatment	Secondary Treatment	N Removal	P Removal	Chlorination	Filtration
>10000 p.e.	32%	100%	91%	62%	88%	22%
<10000 p.e.	35%	100%	70%	52%	78%	15%
all uwwtps	33%	100%	85%	59%	85%	20%

Figure 5. % of UWWTPs and relevant treatment provided

More than 80% of the wastewater treatment plants treat sludge in a thickening-dewatering unit, supplemented by some form of stabilization (aerobic or anaerobic). Almost 40% of the plants perform anaerobic digestion and only 8% provide further treatment of sludge in drying plants.

PERFORMANCE INDICATORS FOR WWTPs WITH CAPACITY LESS THAN 10.000 p.e.

All wastewater treatment plants in Greece with p.e. greater than 2000 are operated by the technical services of the local municipalities or the relevant Municipal Enterprises for Water Supply and Sewerage, who are responsible for the maintenance and operation of the sewerage network and the wastewater treatment plants. The responsible authorities submit monitoring performance data through the open on-line national platform which has been designed and operated for this purpose (http://astikalimata.ypeka.gr/) under the supervision of the Special Secretariat for Water of the Ministry of Environment. Figure 6 presents the data entry form which is used by the operators of the wastewater treatment plants, while in Figure 7 presents the total number of samples that have been reported by the operators of the WWTPs each year. Considering the fact that the database was operational from 2010 most of the samples are related to the period from 2011 onwards. This period was selected for the results analysis that follows, i.e. 2011-2015.



Ημερομηνία	BOD5	COD	SS	T-N	NH4-N	T-P
30/12/2011	404	880	481	68,4		
21/12/2011	518	1148	759	72,6		10,9
16/12/2011	672	1315	844	77,4		
9/12/2011	545	1435	760	78,9		
7/12/2011	1320	1728	1125	101,4		17
2/12/2011	624	1579	810	94,8		

Figure 6. Working environment of the UWWTP database

The total number of samples that was uploaded was more than 230,000 indicating the important set of data available. These samples refer to inlet and effluent concentrations of the following quality parameters BOD_5, COD, SS, TN, NH_4-N, NO_3-N and TP. More data (77%) were reported by the operators of wastewater treatment plants with a capacity greater than 10000 p.e., which is expected considering the fact that their reporting obligations are stricter in terms of the number of samples collected per year. The average number of samples collected per year is 12 for the small and medium sized wastewater treatment plants and almost double for the larger plants (Figure 8).

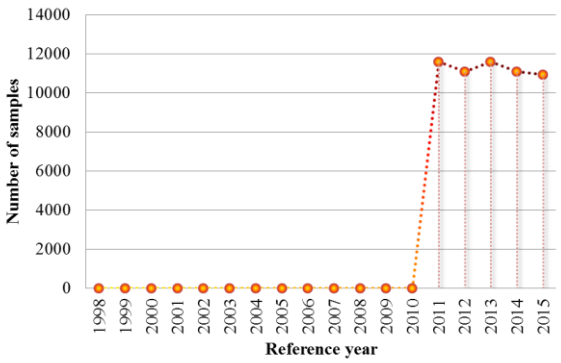


Figure 7. Number of data submitted per reference year

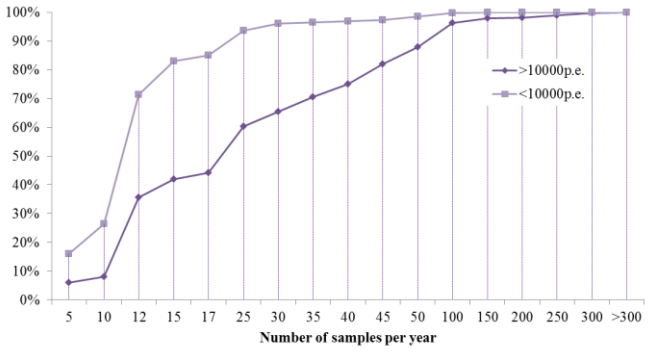


Figure 8. Distribution of samples collected per year

Operational characteristics

Influent concentrations of quality parameters BOD, COD, SS, TN, TP: Influent concentrations are

presented in Table 1 from where it can be seen that the characteristics of wastewater are comparable to typical values of medium strength wastewater, while a small differentiation between small and larger WWTPs is observed, with the former being characterised by lower concentrations (Figures 9 and 10). This could be attributed to the fact that in larger cities sewage is actually mixture of domestic and industrial wastewater.

Table 1. Influent characteristics of WWTPs in Greece

	All data	WWTP capacity		*Typical composition of raw municipal wastewater with minor contributions of industrial wastewater*		
		>10000 p.e.	<10000 p.e.	*High*	*Medium*	*Low*
BOD-mg/l-ave	292	304	250	*560*	*350*	*230*
COD-mg/l-ave	603	639	472	*1,200*	*750*	*500*
SS-mg/l-ave	282	305	197	*600*	*400*	*250*
TN-mg/l-ave	54	55	51,4	*100*	*60*	*30*
TP-mg/l-ave	10	10,2	9,75	*25*	*15*	*6*

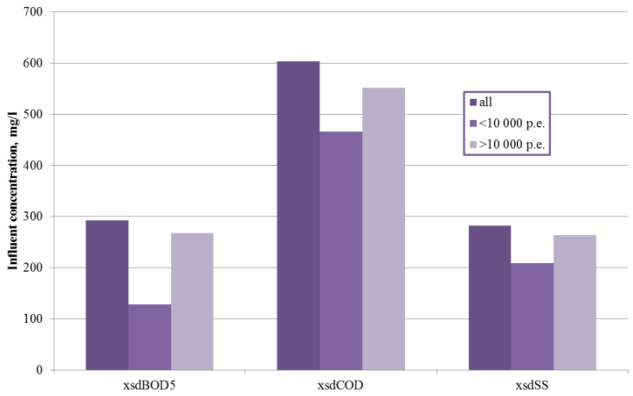


Figure 9: Influent concentrations for organic load and suspended solids

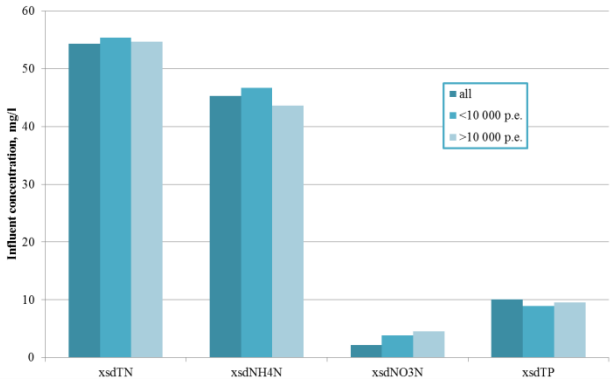


Figure 10: Influent concentrations for nitrogen and phosphorus

With respect to the characteristics of incoming sewage in terms of organic load and flow per capita (Figures 9 and 10), these are close to the typical values of 60 gr/p.e./d for BOD, and 200 L/p.e./d for around 70% and 65% of the WWTPs, respectively. Regarding the parameters of nitrogen and phosphorus, around 75-80% present loads of 12,5 gr/p.e./d and 2.5 gr/p.e./d respectively, which are in close agreement with the typical design values presented in Table 2.

Table 2. Variations in person load (Henze et al., 2002)

Parameter	Unit	Range
COD	gr/cap.d	25-200
BOD	gr/cap.d	15-80
Nitrogen	gr/cap.d	2-15
Phosphorus	gr/cap.d	1-3
Wastewater	m^3/cap.d	0.05-0.40

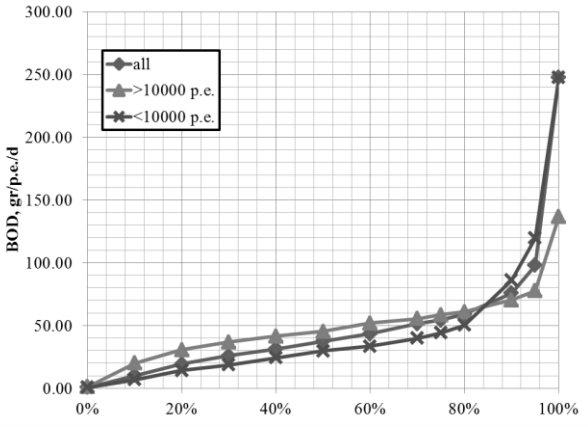


Figure 11: BOD in gr/p.e./d

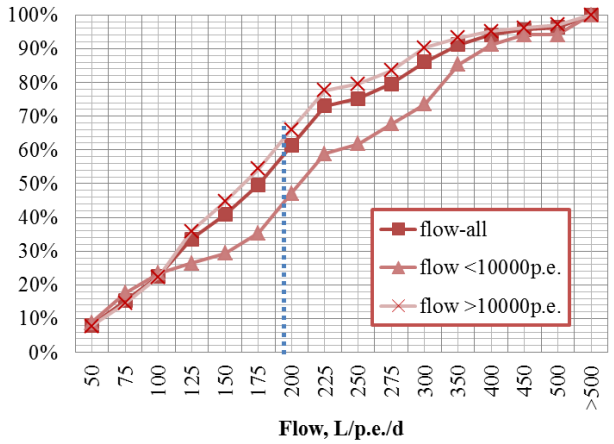


Figure 12: Incoming flow in L/p.e./d s

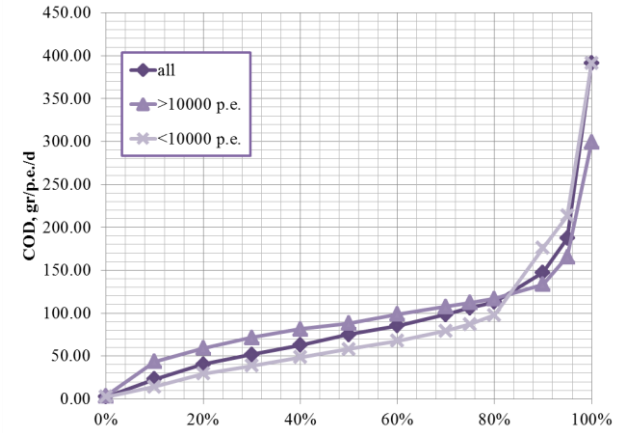


Figure 13: COD in gr/p.e./d

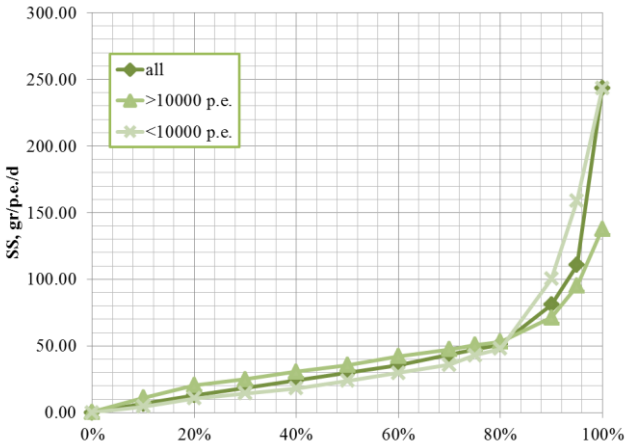


Figure 14: SS in gr/p.e./d

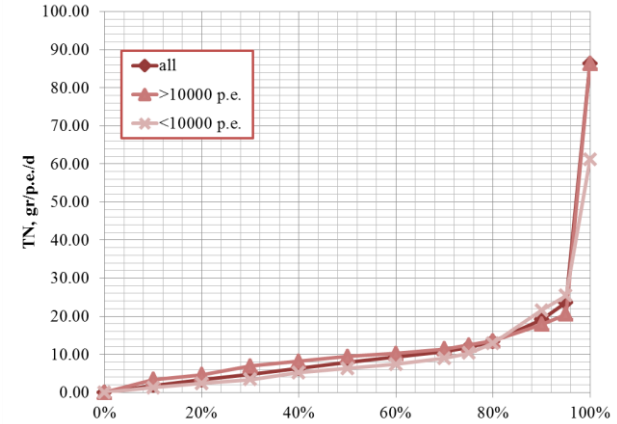


Figure 15: TN in gr/p.e./d

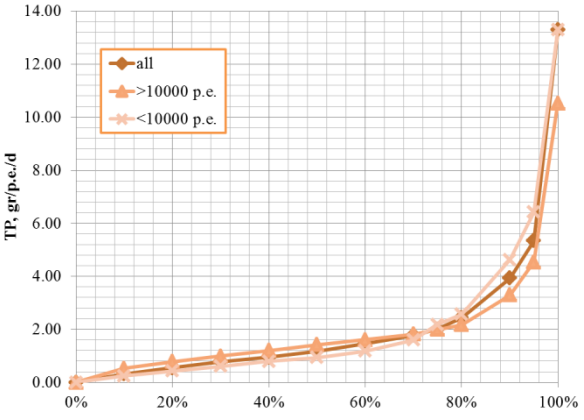


Figure 16: TP in gr/p.e./d

Influent characteristics- Ratios: The ratio between the various components in wastewater has significant influence on the selection and functioning of wastewater treatment processes and usually refers to COD/BOD (Figure 17) and carbon to nitrogen or phosphorus (either COD/TN or BOD/TN). Typical values are presented in Table 3.

Wastewater with low carbon to nitrogen ratio may need external carbon source addition in order that biological denitrification functions fast and efficiently. Wastewater with high COD to BOD ratio indicates that a substantial part of the organic matter will be difficult to degrade biologically.

While most of the pollution load in wastewater originates from households, the industrial wastewater could only partially contribute to the total quantity of sewage. In cases where the contribution of industrial wastewater is significant the ratio between the components may present increased deviation from the typical expected values. Since these discrepancies may affect the treatment process the reason for their appearance should be further investigated. In Greece in general the component ratios describe wastewater with low strength suggesting that the impact of industrial wastewater is limited. Carbon to phosphorus ratio seems higher in larger wastewater treatment plants which could potentially be attributed to industrial wastewater discharges to sewers.

Table 3. Typical ratios in municipal wastewater and relevant figures from Greek WWTPs

	All data	WWTP capacity		*Typical ratios in municipal wastewater*		
		>10000 p.e.	<10000 p.e.	*High*	*Medium*	*Low*
COD/BOD	2.0	2.1	1.8	*2.5-3.5*	*2.0-2.5*	*1.5-2.0*
COD/TN	4.6	4.3	6.7	*12-16*	*8-12*	*6-8*
COD/TP	26.6	27.3	24.0	*45-60*	*35-45*	*20-35*
BOD/TN	2.2	2.1	3.1	*6-8*	*4-6*	*3-4*
BOD/TP	14.6	16.2	10.9	*20-30*	*15-20*	*10-15*

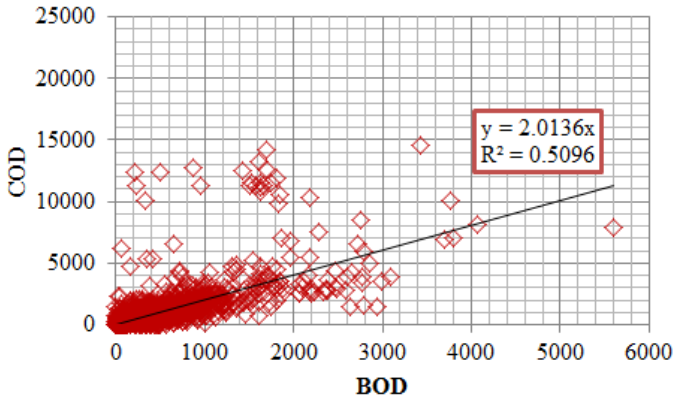


Figure 17. COD/BOD ratio in municipal wastewater in Greece

Effluent characteristics. The ratios of the BOD_5 values for 90% of the samples to the median BOD_5 values vary between 1.32 and 1.60, with the lower ratios corresponding to the smaller scale treatment plants. This could mean that in smaller plants a more consistent effluent quality is obtained, perhaps due to limited in number and magnitude shock loads, which overshadow possible disadvantages in terms of personnel and experience. However, one should be careful in drawing definite conclusion, given that the statistical evaluation may be influenced by the smaller number of data available for small scale units

Accepting a round figure of 1,60 for the ratio and taking into consideration that the 25 mg/l requirement from the Directive refers to the value to be achieved for 88%-93% of the samples, it is wise to design a plant aiming at an average (in fact median) concentration of 15 mg/l. Furthermore, most design models are based on the expected soluble BOD_5 in the reactor, which must be determined taking into consideration the particular BOD_5 due the suspended solids in the effluent. The data provided show that the ratio of SS/BOD_5 is approximately 1. This means that meeting the

SS requirements of the Directive is an easier task in comparison to BOD_5. Moreover, given this ratio of 1 and assuming that 1 mg of SS corresponds to 0.60-0.70 in terms of particular BOD_5, a safe design value for the soluble BOD_5 to be achieved is to the order of 4-5 mg/l.

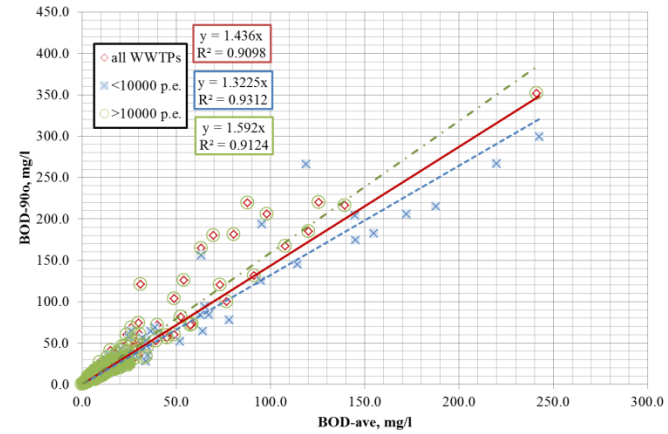


Figure 18. BOD_{90}/BOD_{ave} in effluent

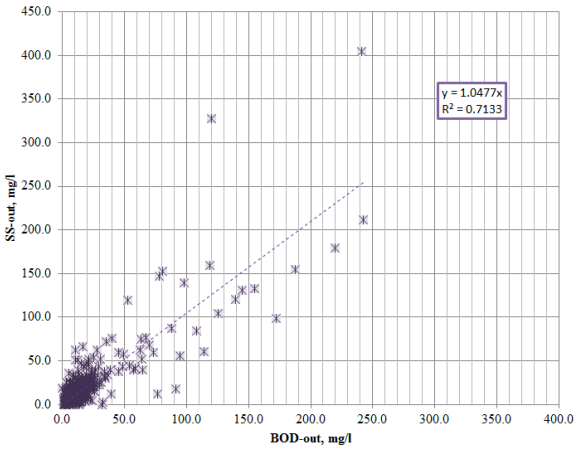


Figure 19. SS/BOD ratio in wastewater effluent

Compliance to discharge requirements

Compliance with the provisions of the UWWTD refers to effluent concentrations of BOD, COD and SS and occasionally nitrogen and phosphorus, depending on the sensitivity of the final recipient. Based on the results from more than 190 WWTPs it is evident that almost 90% of the plants meet the 25 mg/l BOD and 35 mg/l SS effluent standard for the 90% of the samples without differentiation between small-medium sized to large WWTPs. For COD the compliant plants that meet the 125 mg/l effluent standard is close to 95%. With respect to nitrogen, although for most wastewater treatment plants the recipient is characterised as normal and are not subjected to compliance with nitrogen effluent standards, nevertheless more than 80% of the WWTPs efficiently remove nitrogen meeting the 15 mg/l limit for 50% of the samples. For phosphorus less than 45% of the wastewater treatment plants remove phosphorus below the 2 mg/l effluent standard set in the UWWTD for sensitive areas.

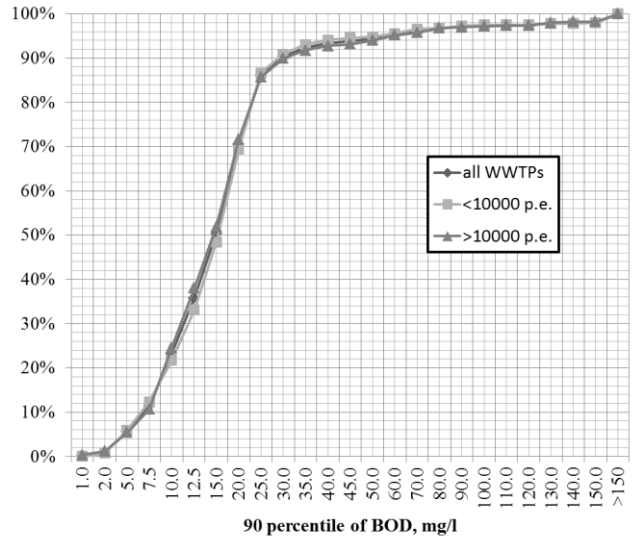


Figure 20. Cumulative distribution of 90 percentile BOD in the effluent

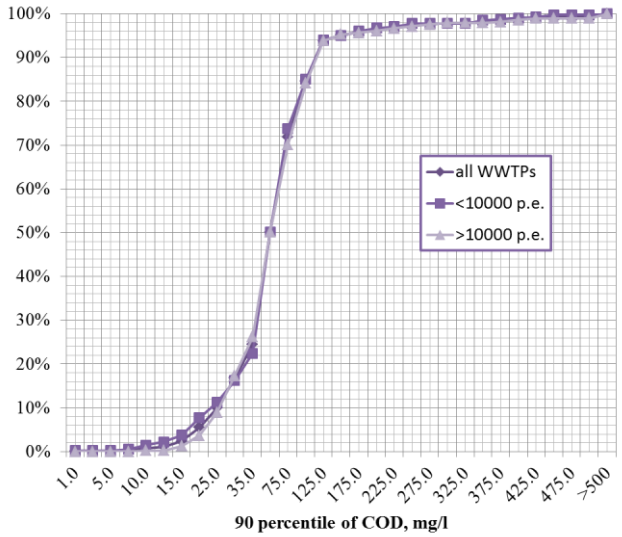


Figure 21. Cumulative distribution of 90 percentile COD in the effluent

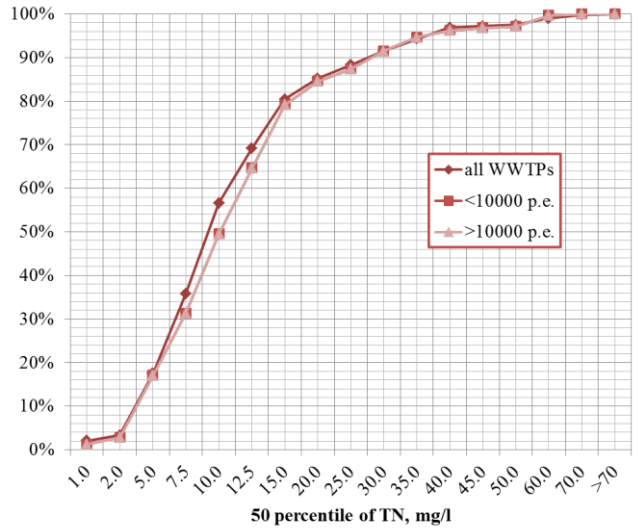


Figure 22. Cumulative distribution of 50 percentile TN in the effluent

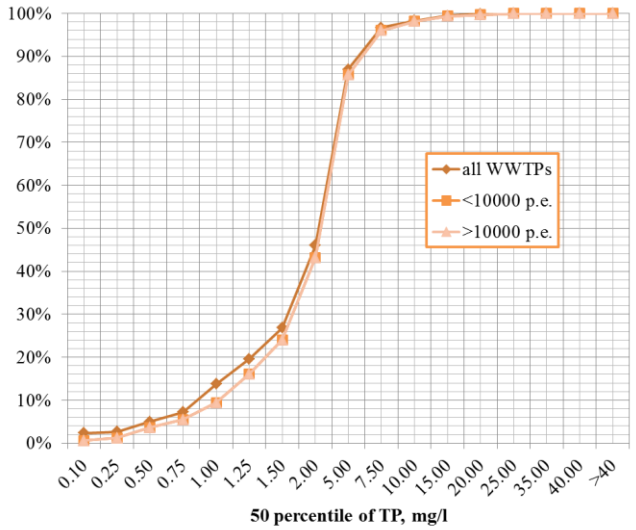


Figure 23. Cumulative distribution of 50 percentile TP in the effluent

CONCLUSIONS

Wastewater treatment on Greece is satisfactory both in terms of the infrastructure, i.e. the WWTPs constructed and respective population served and operation. Wastewater presents the characteristics of low to medium strength which is compatible considering the relatively limited industrial activity in the country. More than 90% of the wastewater treatment plants meet the effluent standards set by the UWWTD for BOD, COD and SS, while it is notable that more than 80% of the plants perform nitrogen removal at satisfactory levels.

ACKNOWLEDGEMENTS

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