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Outstanding Student Poster & PICO Contest

Investigation of stochastic similarities among influent and treated effluent variables of spatially distributed wastewater treatment plants in Greece; II: Statistical analysis of treated effluent variables in terms of the marginal distribution

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HS3.2: Spatio-temporal and/or (geo)statistical analysis of hydrological events, floods, extremes and related hazards

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1.Introduction

Urban Wastewater Treatment Directive (UWWD-91/271/EEC) is one of the main environmental protection policy instruments in the framework of water resources management. The incorporation of the Directive and the compliance to the requirements led during the last twenty five years to the construction and the upgrading existing wastewater treatment plants in Greece. In particular in 2014, Greece had 455 urban waste water agglomerations of more than 2.000 population equivalent (p.e). These agglomerations generated a total load of 11.790.586 p.e., 90% of this load is connected to collecting systems and 10% addressed through Individual and Appropriate Systems (storage or septic tanks, micro-stations). (https://uwwtd.eu/Greece). Most of the Greek WWTPs , about 77%, operate as extended aeration activated sludge systems providing sludge stabilization in the biological stage, whereas the 23% of them combine primary with biological treatment and the primary sludge stabilizes by anaerobic digestion.

As far as disinfection concerned the most widely used method is chlorination, while UV and ozonation seems to appear in a low percentage of total amount of WWTPs in Greece yet.
In parallel to the improvement of the effluent quality, the sewage sludge produced in WWTPs rise an awareness for the problems associated with sludge, which includes the continuous increase in the amounts of dry solids produced, considerable costs due to the management of high volume with low content of dry sludge solids before disposal and in addition significant risks on environment and human health due mainly to heavy metals and pathogens that may be present.

Type of treatment	Equivalent Population Served	Percentage%
Secondary treatment	14.233	0,1
N-Removal	7.501.533	67,6
NP-Removal	2.793.043	25,2
P-Removal	27.274	0,2
Other treatment	14.233	0,1
total	**11.092.016**	**100**

Table 1.1. Population equivalent both in absolute numbers and percentages that are being served by different type of wastewater treatment in Greece (source: tps://uwwtd.eu/Greece).

WWTP size	Equivalent Population Served	Percentage %
<10.000 p.e.	254.501	2,3
10.000-100.000 p.e	2.837.162	25,6
>100.000 p.e.	8.000.353	72,1
total	**11.092.016**	**100**

Table 1.2. Population equivalent both in absolute numbers and percentages that are being served by different size of wastewater treatment plants in Greece (source: https://uwwtd.eu/Greece).

2.What's the aim of this research?

This research is carried out in order to investigate if there are any statistical similarities among treated effluent wastewater characteristics (and among effluent with influent marginal estimates) of spatially distributed WWTPs in Greece. The aim is to estimate the most appropriate model (in terms of the marginal distribution) for the WWTP treated effluent variables through a pooled analysis (Dimitriadis and Koutsoyiannis, 2018). Any conclusions produced from this study could be used for further investigation and contribute to the understanding of the statistical characteristics of treated wastewater.

3.From where the data have been collected?

The data downloaded from the Greek national database of wastewater treatment plants (http://astikalimata.ypeka.gr) uniformly distributed over Greece. The available information for each variable was daily concentration measurements.

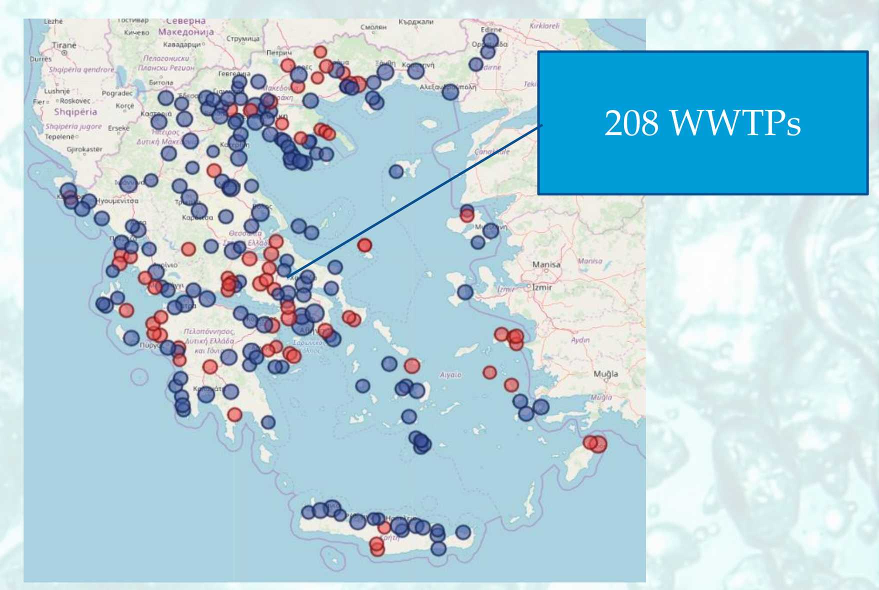
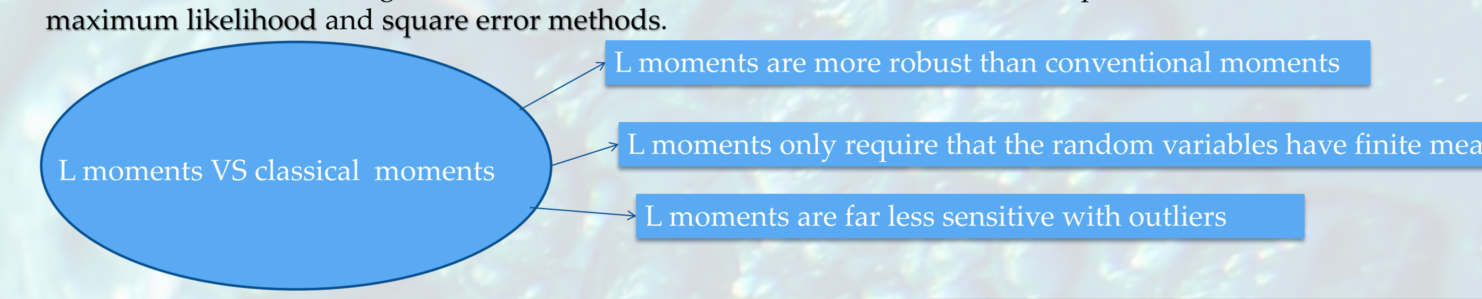


Figure 3.1. Wastewater treatment plants from the National Database in Greece.

4.Materials & Methods

This study focuses on the statistical analysis of **treated effluent** variables in terms of the marginal distribution. Statistical parameters are being analyzed over all Greek WWTPs in order to observe the fluctuations and the similarities of the important variables. The variables which are being examined are BOD_5, COD, SS, T-N, NH_4-N, NO_3-N, T-P effluent concentrations.
For each WWTP both the **first four classical moments** and **L moments** have been estimated (average, standard deviation, skewness and kurtosis) for each parameter of interest.
Furthermore, for the two largest WWTPs in Greece, that are serving almost the half of the country's population, classical and L moments have also been estimated for each month in order to observe the variability among seasons. In addition, for those WWTPs with the highest capacity, well-known distributions applied in order to investigate if the variability of the treated effluent parameters could be simulated successfully by a well known distribution. The distributions that were examined are Gamma, Log-Normal, Weibull and Normal. For each of them, the parameters needed were calculated using **maximum likelihood** and **square error methods.**



L moments	Classical moments
$L1=b_0$	E[x]
$L2=(2\times b_1)-b_0$	$E[(x-m)^2]$
$L3=(6\times b_2)-(6\times b_1)+b_0$	$E[(x-m)^3]$
$L4=(20\times b_3)-(30\times b_2)+(12\times b_1)-b_0$	$E[(x-m)^4]$

Table 4.1. L and classical moments , whereas b_i coefficients are the partial estimations of probabilistically, weighted moments.

L moments coefficients	Classical moments coefficients
L2/L1	$E[(x-m)^2]/ E[x]$
L3/L2	$E[(x-m)^3]/ E[(x-m)^2]$
L4/L2	$E[(x-m)^4]/ E[(x-m)^2]$

Table 4.2. Coefficients of both L and classical moments.

Spatial analysis of the marginal estimates for all the WWTPs in Greece was carried out so as to research whether the marginal statistics of the selected variables occur any kind of correlation (linear, logarithmic, and exponential) among treated effluent variables and between influent and effluent characteristics.
Furthermore, the relationship between skewness and kurtosis and coefficients L3/L2, L4/L2 was examined if they could be followed by a known distribution: max PBF, min PBF, Weibull, Log Normal, Gamma, Rayleigh.
Eventually, probability distribution functions and Cumulative distribution functions were created in a procedure to estimate the amount of the daily specific dry solids production per capita by taking into consideration the capacity of max equivalent population of all WWTPs in Greece.

5.Results

	BOD_5		COD		SS		TN	
WWTP size	Average	St.dev	Average	St.dev	Average	St.dev	Average	St.dev
< 10.000 p.e	24,7	16,9	72,1	45,4	26	21,7	15,0	7,2
10.000-100.000 p.e.	12,0	7,4	41,9	25,9	14,0	11,4	12,1	6,8
>100.000 p.e.	9,2	5,3	38,4	19,3	12,9	9,3	9,2	4,1

Table 5.1. Average and standard deviation values for treated effluent BOD_5, COD, SS and TN that conducted from spatial analysis.

•It is observed that as the capacity of the WWTP rises, both the average and the standard deviation decreases. The average value of the BOD_5, COD, SS and TN are consistently lower than the regulated limits established through UWWD (25 mg/l for BOD_5 , 35 mg/l for suspended solids, 125 mg/l for COD, 10-15 mg/l for total nitrogen depending on the population equivalent.

Average=a*L2+b

	a	b	R^2
BOD_5	2.39	4.79	0.74
COD	2.28	17.14	0.69
SS	2.10	4.48	0.87
TN	2.38	5.52	0.74
NH_4-N	1.62	0.00	0.93
NO_3-N	1.75	3.20	0.52
TP	1.62	1.52	0.65

Table 5.2. Coefficients of linear correlation between average and L2 moment of treated effluent variables, conducted from spatial analysis.

•The relationship between average and L2 moment occurred linear for all the effluent variables presenting the lowest correlation coefficient for NO_3-N and the highest for NH_4-N.

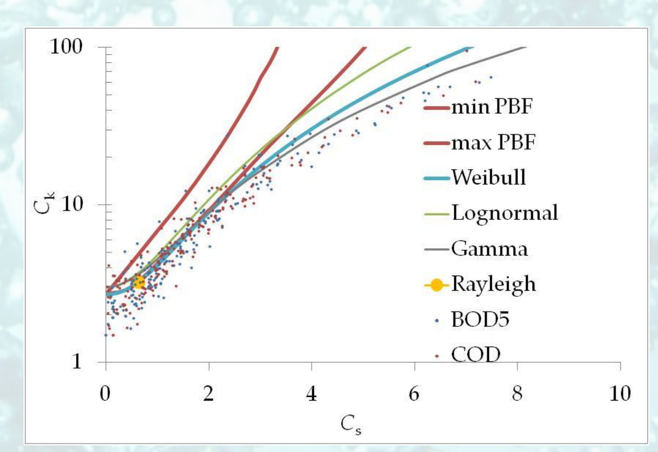


Figure 5.1. Coefficient of kurtosis vs. coefficient of skewness for treated effluent BOD_5 and COD, conducted from spatial analysis.

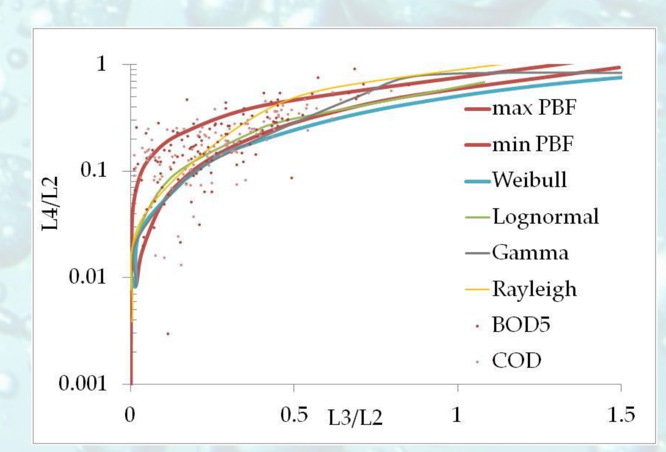


Figure 5.2. Coefficient L4/L2 vs. Coefficient L3/L2 for treated effluent BOD_5 and COD, conducted from spatial analysis.

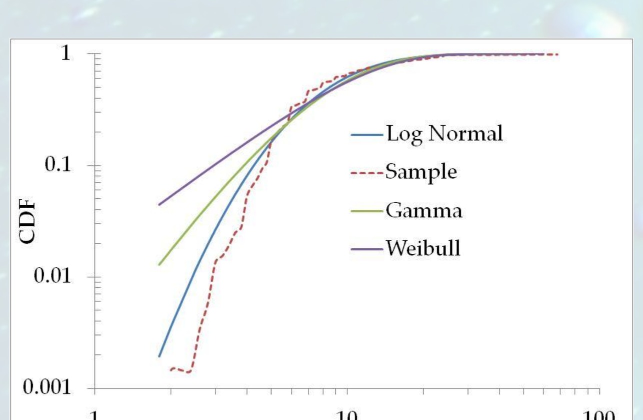


Figure 5.3. Cumulative Distribution Function of BOD_5 for sample and for well known distributions for Psyttalia (parameters of well known distributions calculated applying maximum likelihood).

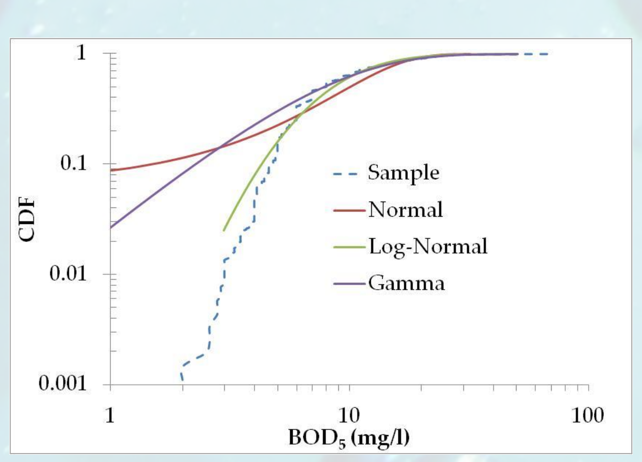


Figure 5.4. Cumulative Distribution Function of BOD_5 for sample and for well known distributions for Psyttalia (parameters of well known distributions calculated applying square error method).

•For the largest WWTP in Greece (serving a population equivalent of 5.200.000), the Log Normal distribution fits better to variable BOD_5 when applying both maximum likelihood and square error methods. When it comes to COD and SS Log Normal seems again as the most appropriate distribution. Maximum likelihood indicate both Log Normal and Gamma appropriate for TN, whereas square error showed that Log Normal fits better.

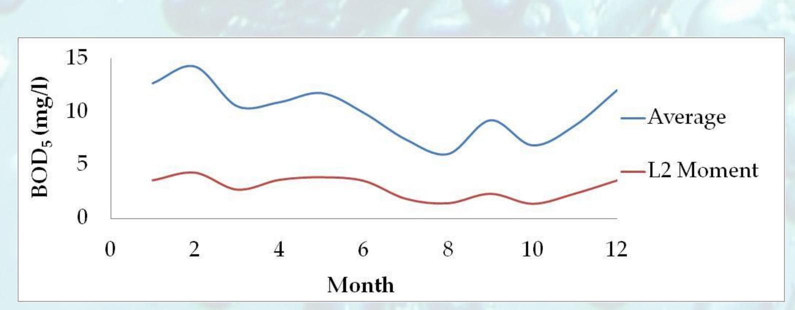


Figure 5.5. Seasonal average values and L2 moment of treated effluent BOD_5 for Psyttalia.

•Average treated effluent BOD_5 concentration values decrease during summer period due to the temperature dependence of all biochemical processes (i.e. the increase of temperature results to the increase of the biological activity of heterotrophic bacteria which consume organic carbon as an energy and carbon source).
L2 moment occurs smaller fluctuations than average among months.

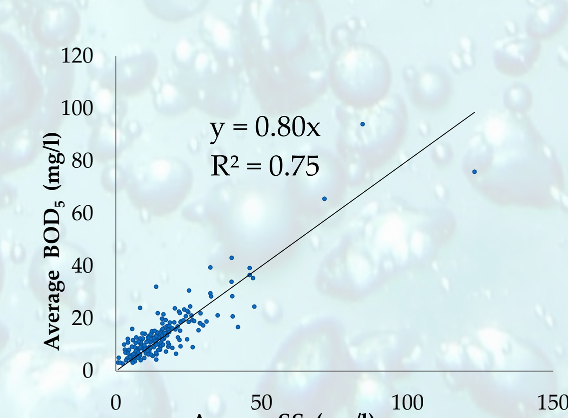


Figure 5.6. The relationship between averaged treated effluent BOD_5 and averaged treated effluent SS, conducted from spatial analysis.

•A typical value for the ratio BOD_5 /SS effluent is approximately 0,6-0,7 . The linear correlation between average values of treated effluent BOD_5 and SS indicates that the value of the ratio mentioned is about 0,80.

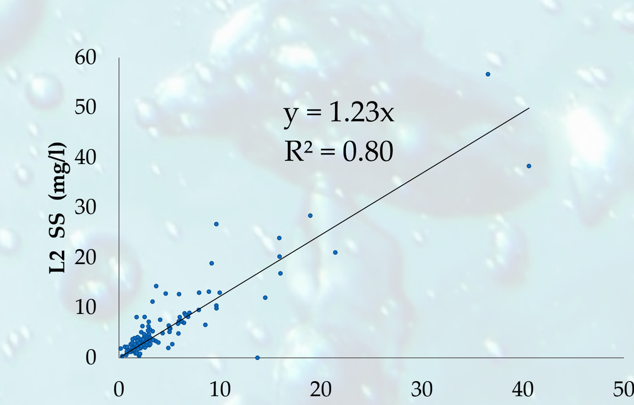


Figure 5.7. The relationship between L2 moment of treated effluent SS and L2 moment of treated effluent BOD_5, conducted from spatial analysis.

6. Further Discussion

As far as energy recovery from sludge concerned, the organic component of sludge can provide a heat value of approximately 25 MJ/kg dried solids. However, taking account the inert fraction the real value is **16-20 MJ/kg DS** for raw sludge and **10-14 MJ/kg DS** for digested sludge. The most common energy producing sludge treatment method used is anaerobic digestion with subsequent utilization of the produced biogas. Information provided from the national database for 208 WWTPs in Greece shows that 13 of them implement anaerobic digestion and only 2 of them thermal drying following anaerobic digestion and sludge dewatering. The biogas produced during anaerobic digestion is then burnt in combined heat and power units, resulting to energy production in the form of electric power (almost 35% of the total) and heat (almost 50% of the total).

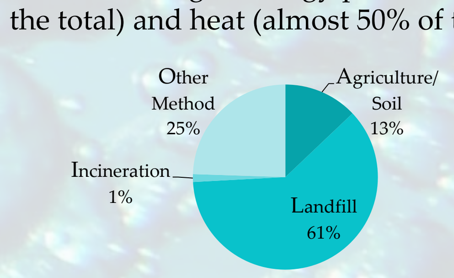


Figure 6.1. Disposal methods of produced sewage sludge in Greece.

107.563 ton of dry solids produced annually from 142 WWTPs

7. Conclusions

•Linear correlation resulted between average and L2 moment for each and every of treated effluent variables. Average and L2 moment were also examined among treated effluent and influent variables in different combinations among them but no important linear correlation occurred except for BOD_5 influent-effluent for WWTPs with high capacity (p.e>100.000).
•Log Normal & Gamma distribution seems to fit better treated effluent BOD_5, COD ,SS and TN for the two largest WWTP in Greece (Psyttalia & Thessaloniki), serving 6.123.523 population equivalent.

Links

https://uwwtd.eu/Greece/
http://astikalimata.ypeka.gr/Default.aspx

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