Investigation of stochastic similarities among entrance and outflow variables of spatially distributed waste water treatment plants in Greece; I: Statistical analysis of entrance variables in terms of the marginal distribution

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Outstanding Student Poster & PICO Contest

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1. INTRODUCTION

The last 25 years, Greece presents a remarkable improvement on Wastewater management. The implementation of Urban Wastewater Treatment Directive (91/271/EEC), contributed significantly to the construction and operation of 234 Wastewater Treatment Plants (WWTPs) until 2014. In particular, Greece has 455 urban waste water agglomerations of more than 2000 population equivalent (p.e) and their total load corresponds to 11.790.586 p.e. 90% of this load is connected to collecting systems and 10% addressed through Individual and Appropriate Systems (IAS). All these treatment plants have a total capacity of 13.982.384 p.e. Most of the Greek WWTPs (77%) consist of activated sludge system based on extended aeration and sludge stabilization carried out in biological stage, while 23% of WWTP have a primary treatment stage along with biological stage and sludge stabilization achieved through anaerobic digestion.

WWTP size	Served population(p.e.)	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 1.1 Served population for WWTP of different size

(source: Urban Waste Water Treatment Directive (UWWTD) site for Europe)

Type of treatment	Served population (p.e.)	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 1.2 Served population for every type of treatment

2. AIM OF RESEARCH

This research is carried out as part of the investigation of statistic similarities among influent and treated effluent variables of spatially distributed WWTPs in Greece. The objective of the particular study is the statistical analysis of influent variables. It is significant to make an overall approach of all the WWTPs and examine their marginal statistics, as well as focusing on specific WWTPs of important capacity. For each of the targeted influent variable (BOD_5, COD, SS, T-N, NH_4-N and T-P) the best fitted probability distribution has been examined. The aim is to estimate the most appropriate model (in terms of the marginal distribution) for the WWTP influent variables through a pooled analysis (Dimitriadis and Koutsoyiannis, 2018). The findings of this study can contribute to the understanding of the statistical properties of wastewater influent characteristics which can be used to create influent generation formulas for risk analysis studies.

Image 3: Waste Water Treatment Plants from the national data base in Greece

3. DATA

Data used for the analysis were collected from the national database of Greek waste water treatment plants (http://astikalimata.ypeka.gr), where spatial information (location, treated population) is uniformly distributed over Greece. In this database access to daily measurements of inflow and outflow parameters (BOD_5, COD, SS, T-N, NH_4-N, NO_3-N and T-P) is provided. However, the discontinuity of data in a couple of WWTP even for long periods of time, is important.

BOD_5 (Biochemical Oxygen Demand) and COD (total Chemical Oxygen Demand) account for the organic load of wastewater. BOD_5 defines the biodegradable organic load while COD defines both the biodegradable and non-biodegradable organic carbon. The biological processes taking place in WWTP result only in the reduction of biodegradable load. Therefore, influent COD/BOD_5 is expected to be around 2-2.2 while effluent COD/BOD_5 is expected to be around 5 (due to the biological treatment).

The fraction BOD_5/T-P in influent wastewater reflects the potential for biological phosphorus removal. Polyphosphate Accumulating Bacteria (PAOs) responsible for biological phosphorus removal, consume organic carbon and therefore higher values of BOD_5/T-P stimulate PAOs growth and phosphorus removal. Based on an averaged BOD_5 and T-P daily specific production in influent wastewater of 60 g/capita/d and 2.5 g/capita/d respectively, a typical value for BOD_5/T-P ratio to the order of 24 is calculated.

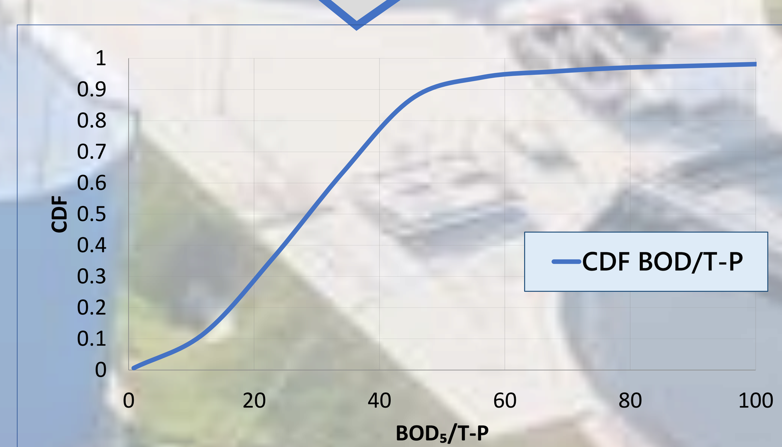

Figure 3.4: Cumulative probability function for BOD_5/T-P influent for the total amount of WWTPs in Greece

The averaged value for BOD_5/T-P is 30.2 while the typical value is 24. Moreover, the possibility that this parameter is under 24 is less than 40%. Based on these values it is anticipated that enough organic carbon is provided to enhance biological phosphorus removal at Greek WWTPs.

4. MATERIALS AND METHODS

1) Statistical analysis on inflow variables (BOD_5, COD, SS, T-N, NH_4-N, T-P) required the estimation of marginal statistics for each of them. Specifically, for each WWTP the following statistics were estimated:

- first four classical moments (mean, Standard deviation, Skewness and Kurtosis)
- first four L moments (L1=mean, L2, L3, L4)
- coefficients for both classical and L moments

Estimation of probabilistically weighted moments	L moments	Classical moments
$b_o = \left(\frac{1}{n}\right) \sum_{k=0}^{n} X(j)$	L1=bo	E[x]
$b_1 = \left(\frac{1}{n}\right) \sum_{k=0}^{n} (1-(j-0.35)/n)) * X(j)$	L2=(2×b1)-bo	$E[(x-m)^2]$
$b_2 = \left(\frac{1}{n}\right) \sum_{k=0}^{n} (1-(j-0.35)/n))^2 * X(j)$	L3=(6×b2)-(6×b1)+bo	$E[(x-m)^3]$
$b_3 = \left(\frac{1}{n}\right) \sum_{k=0}^{n} (1-(j-0.35)/n))^3 * X(j)$	L4=(20×b3)-(30×b2)+(12×b1)-bo	$E[(x-m)^4]$

Table 4.1 Calculation of b coefficients, L moments and classical moments (D. Koutsoyiannis, 1997)

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 Calculation of L and classical moments' coefficients (D. Koutsoyiannis, 1997)

2) Based on the above equations for each variable a series of calculations were implemented as follows:

➢Overall marginal statistics for every WWTP
➢Seasonal marginal statistics for specific WWTP (Psyttalia)

3) Spatial analysis of these marginal statistics was carried out and particularly the correlation between different statistical parameters (e.g. mean-L2, L3-L4, Cs-Ck) and different variables (e.g. BOD_5/T-P influent - T-P effluent, COD/BOD_5 influent, NH_4-N - T-N influent) were examined.

4) Spatially analyzed marginal statistics were fitted to many distributions (Max PBF, Min PBF, Log-Normal, Gamma, Weibull, Reyleigh)

5) Two different methods (square error and maximum likelihood) were implemented for different types of distributions (Normal, Log-Normal, Gamma, Weibull) to define which one fits better in each of the influent wastewater variables (BOD_5, COD, SS, T-N, NH_4-N, T-P). The WWTP where the fitting was implemented was Psyttalia and Thessaloniki, because they have the largest treatment capacity.

5. RESULTS

•Fitting distributions

In order to define which distribution can most appropriately fit the incoming load, the maximum likelihood and square error methods were applied. The most appropriate distributions for BOD_5 for both Psyttalia and Thessaloniki WWTP are the Log Normal and Gamma distributions, according to both methods. On the other hand, Normal distribution was less appropriate, and Weibull distribution the less appropriate!

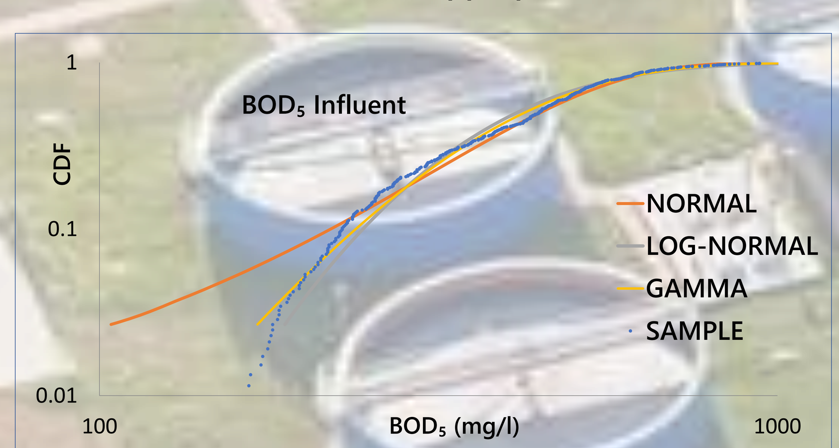

Figure 1: Influent BOD_5 distribution in Thessaloniki WWTP

•Seasonal marginal statistics

Monthly mean and standard deviation values of data from specific WWTP were estimated, to examine the seasonality. Mean values are lower in summer period.

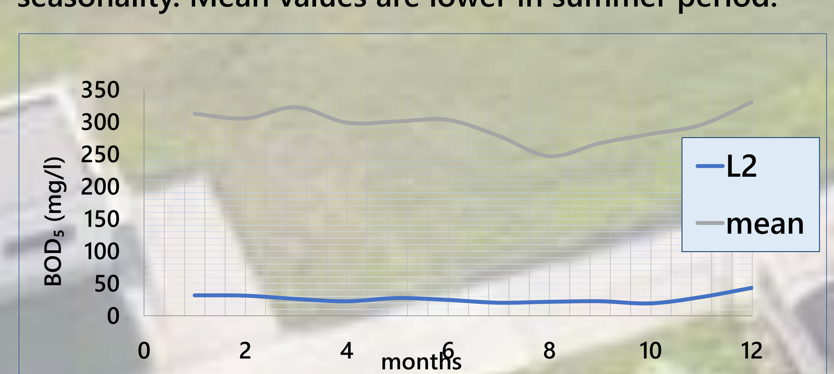

Figure 2: Seasonal mean and L2 moments

•Spatial analysis

- There is a high linear correlation among 3[rd] and 4[th] moments of influent BOD_5, COD, SS, T-N and T-P of WWTP distributed spatially in Greece. Particularly correlation (R^2) is between 0.7 and 0.97 for the above variables.
- The linear correlation between 1[st] and 2[nd] moments is not adequate for every variable. Only NH_4-N perform correlation up to 0.7.

	a	b	R^2
BOD	2.22	108	0.51
COD	2.4	244	0.54
SS	1.74	95.64	0.6
T-N	2.37	31.17	0.43
NH_4-N	3.38	16.18	0.708
T-P	1.45	5.8	0.534

Table 5: Correlation between 1[st] and 2[nd] L moments:

- High levels of correlation are observed in specific cases. R^2 between L3 and L4 moments for T-P influent is 0.959!

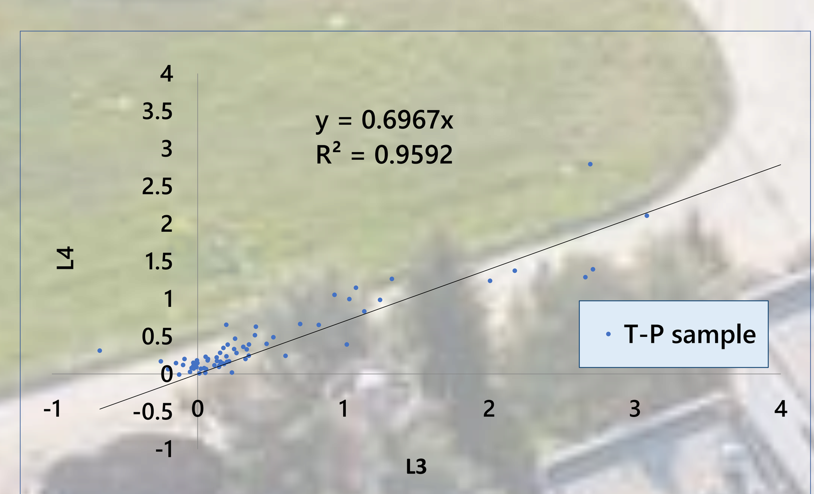

Figure 3.1: Linear correlation between L3 and L4 moments of T-P (total phosphorus) influent from WWTP spatially distributed in Greece

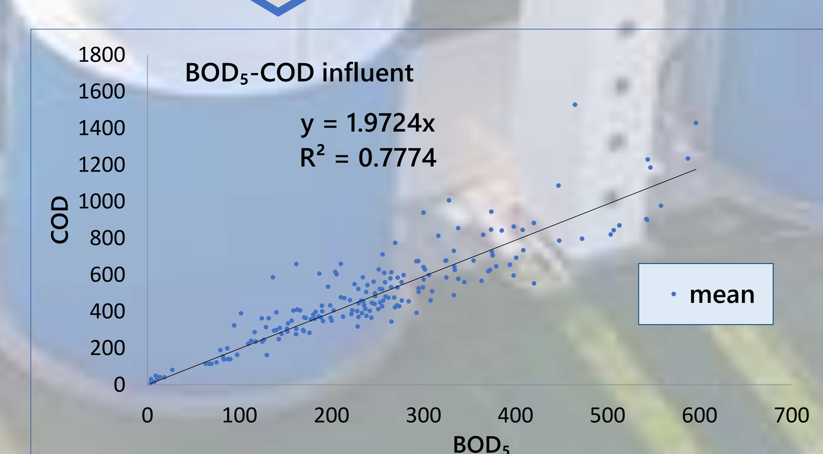

Figure 3.2: Linear correlation between averaged BOD_5 and COD influent from WWTP spatially distributed in Greece

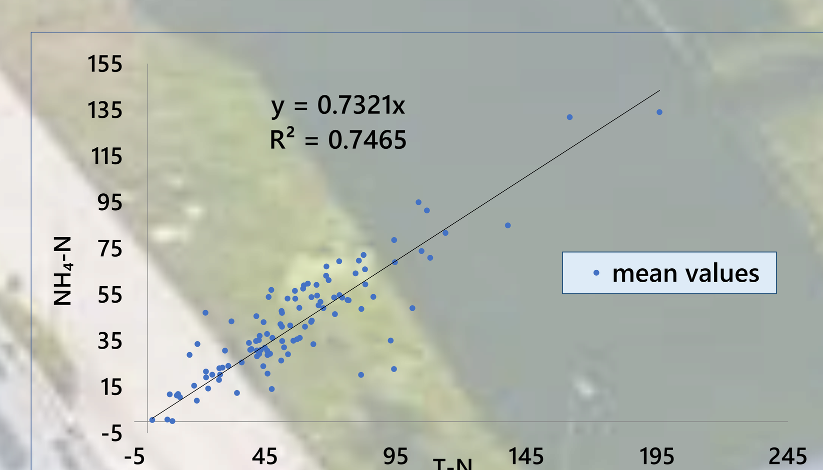

Figure 3.3: Linear correlation between averaged NH_4-N and T-N influent from WWTP spatially distributed in Greece.

•Spatial analysis of classical and L moments and fitting to distributions:

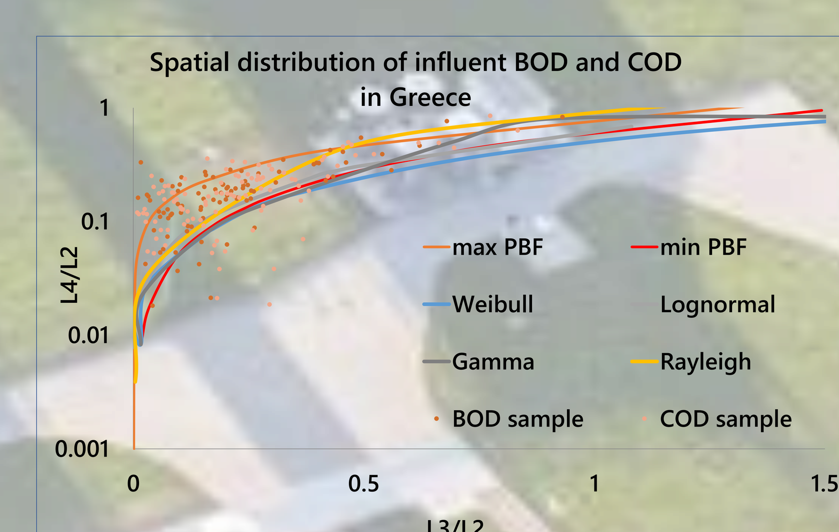

Figure 4: Coefficient L4/L2 VS coefficient L3/L2 for influent BOD_5 and COD conducted from spatial analysis

6. CONCLUSIONS

➢There is a rather good correlation between average BOD_5 and COD influent. The equation that expresses this relation is: COD=1.97·BOD_5

➢In the attempt το fit distributions to the BOD_5 sample, taking into consideration some of the largest WWTP in Greece (of total p.e. 6.123.532), Log-Normal and Gamma distributions present a better fitting than Weibull distribution. The same tendency appears in influent and effluent variables.

Interesting note…
There is a high correlation between L3 and L4 moments of all influent variables. Further investigation on it, could help to find an appropriate distribution that responds to influent variables.

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LINKS

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

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