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The Use of Fuzzy Estimators for the Construction of a Prediction Model Concerning an Environmental Ecosystem

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Abstract: As a variable system, the Lake of Kastoria is a good example regarding the pattern of the Mediterranean shallow lakes. The focus of this study is on the investigation of this lake's eutrophication, analyzing the relation of the basic factors that affect this phenomenon using fuzzy logic. In the method we suggest, while there are many fuzzy implications that can be used since the proposition can take values in the close interval [0,1], we investigate the most appropriate implication for the studied water body. We propose a method evaluating fuzzy implications by constructing triangular non-asymptotic fuzzy numbers for each of the studied parameters coming from experimental data. This is achieved with the use of fuzzy estimators and fuzzy linear regression. In this way, we achieve a better understanding of the mechanisms and functions that regulate this ecosystem.

Keywords: implications; fuzzy estimators; lake eutrophication; prediction model

1. Introduction

Water resources are considered to be a valuable commodity of inestimable value. However, because of the effects of climate change (desertification—drought, water rise, floods, groundwater pollution, coastal erosion and erosion, wetland degradation; heat waves—fires, windstorms or siphons, reduction of biodiversity, etc.) and human intervention, the quality of surface and groundwater is continuously degrading and drinking water reserves are constantly decreasing [1–3]. Meanwhile, the need for increased use of water resources stems from population growth and ever-increasing demands on water and food, but also from the growth that generates activities and hence demands larger quantities of water. Unfortunately, urban water bodies usually have limited surface areas and poor mobility. As a result, they are susceptible to ecological deterioration with smaller water bodies and experience the phenomenon of eutrophication [4]. Strict measures should be taken by authorities in order to preserve and restore the quality and quantity of water basins [5,6], especially in areas that have been categorized as climate change hot spots, such as the Mediterranean Basin.

The extremely limited amount of freshwater on our planet, coupled with the imminent climate change, global warming due to greenhouse gas emissions, and rising water demand, put the availability of water in critical condition and make it imperative to develop control and management systems that aim to optimize the disposal of water resources, which is now called Water Resources Management. The Intergovernmental Panel on Climate Change reports that the climate warming in our century has regionally influenced the global water cycle [7].

One of the most important objects of investigation in Water Resources Management is lake ecosystems, which are environmental goods of particular importance. The lakes are associated with aquatic ecosystems with multiple significance and value, both for humans and for the natural environment. Their water is used in a variety of ways (e.g., water, irrigation, industry), but very often they become the final recipients of urban, industrial, and agricultural waste. This results in the pollution of their waters and disturbance of the ecological balance of the lake ecosystem. Many lakes, in Greece and around the world, face significant water quality problems, which are the subject of intense study by scientists [8,9]. Specifically for the lakes in the Mediterranean, researchers face more complex mechanisms because of the concentrations of phosphorus and nitrates [10].

In Western Macedonia and in the western part of Kastoria Prefecture, Lake Kastoria spreads around the homonymous city. As far as its biological status is concerned, it is a eutrophic lake with lakeside forests, rich in fish and birdlife. The city and the communities that are built on its banks and the catchment area have been heavily burdened by the waters of the lake. Since 1990 a sewage treatment plant has been operating in the city and the lakeside villages, resulting in gradual upgrading of water quality and wetland life. However, fertilizers and pesticides still used on a large scale in agriculture crops in the lakeside area pollute the soil and the underground aquifer, with the lake as the final recipient. This situation has the effect of enhancing the eutrophication of Lake Kastoria.

The lake concentrates the waters of a large catchment area with many watercourses, but through them travel fertilizers and various nutrients along with toxic substances that lead to the eutrophication phenomenon and consequently the degradation of water quality [11]. The amount of dissolved oxygen in water is an indicator of its pollution. The solution of re-cooling the water is not always able to restore the dissolved oxygen values to the levels necessary for the proper aquatic life. In order to study the quality of the Kastoria lake waters, the quantities of dissolved oxygen, as well as some factors affecting or affected by the above (e.g., temperature, pH) have been measured.

The interpretation and prediction of physical, chemical, and biological functions of lakes has so far been studied using widely available empirical and dynamic models along with multi-criteria analysis methods such as WASP5, EUTROMOD, PCLake, and CAEDYEM.

The theory of fuzzy logic is now being applied in several research studies relevant to the assessment of water quality and the trophic state of aquatic ecosystems [12,13]. The fact that fuzzy logic better approaches human logic makes this method more realistic for the description of complex systems like these when compared to classic logic. Multifactor systems such as lakes are governed by some rules. In classic logic, these rules/implications depend only on the question "is the statement true or not true?". All propositions take the values 0 or 1—holds or does not hold. In fuzzy logic, the true or false of a fuzzy proposition take values in the close interval [0,1]. Consequently, fuzzy implications generalize those of classical logic [13].

The key of the investigation of these complex systems is the use of the proper fuzzy implication, using fuzzy estimators for the construction of fuzzy numbers. Moreover, by applying fuzzy linear regression [14], we observe that by comparing the results from fuzzy estimators, we take the same implication which describes the best-studied ecosystem. In this study, we find the fuzzy implication that best describes the studied Lake Kastoria. The ability of selecting the most appropriate implication among others for each study case and calibrating the fuzzy inference systems is a useful tool for the construction of an accurate prediction model. By having such a model, every researcher can achieve a better understanding of the mechanisms that affect the biological and chemical functions in the ecosystem.

2. Materials and Methods

2.1. Study Area

Lake Kastoria is located in the northwestern part of Greece in the mainly mountainous prefecture of Kastoria, with limited cultivated land—most of which is lakeside, as shown in Figure 1. The lake is at an altitude of 630 m. Its area is about 28 km^2,with a maximum depth of about 9 m. Its geographical coordinates at the center are: latitude 40°31′N and longitude 21°18′E [15]. Its water volume is approximately 100,000,000 cubic meters and its coastline is 30.8 km.

(a) (b)

Figure 1. The location of the study case: (**a**) the map of Greece, (**b**) Lake Kastoria.

The lake is fed by many lakeside sources and by the rainwater that either falls directly to its surface or ends up in it with the surface runoff through the torrents located mainly in its northern and eastern parts. In the southern part, a canal (Guilli stream) connects the lake with the Aliakmonas River, where the excess water is drained using a gate that was recently modernized by the Municipality of Kastoria.

A very important natural ecosystem with diverse individual habitats supports a large biodiversity including rare and endangered species. The most typical ones are four species of herons, Dalmatian pelicans, mute swans, wild ducks, night herons, pygmy cormorants, cormorants, and many waterside birds. In addition, it is the only natural lake in Greece where there are still significant riparian forests of hydrophilic trees, which today are one of the rare habitats in the European area. In terms of fishing, Kastoria is the second most productive lake. The fish species inhabiting the lake are the following: perch, carp, chub, wells, muskellunge, roach, and butterfly ray. The existence of a great variety of plants and animals next to a highly developed city is truly remarkable. For the above reasons, the lake is protected by national and international institutional frameworks and since 1974 has been designated by the Ministry of Culture as a Monument of a Special Natural Beauty.

The fact that the lake has been registered with the Nature Network 2000 (GR 1320001) is an element that places the lake area as a priority in promoting the creation of such protection and management structures.

2.2. Database and Model Application in Lake Kastoria

In order to estimate the eutrophic status of this ecosystem, we investigated four of the most representative factors that influence the trophic status of a waterbody. For this research, we used the average measurements of four sampling stations. They were taken every fifteen days for a total duration of 24 months (2015–2017) with the following parameters as depicted in the Appendix A. For this research, the Department of Environment and Water Policies of Kastoria provided the measured data stated below:

- Water temperature: Temperature is directly related to the solubility of oxygen, the metabolism of aquatic organisms, and the process of decomposition of the organic substances it contains. The rise in temperature results in a reduction in dissolved oxygen, necessary for the survival of the aquatic organisms, and reduces the water density. The lightest water rises to the surface and stays there, creating a warmer layer with lower atmospheric oxygen dissolution capacity [16]. This may be fatal for organisms housed or preserved in water (e.g., plankton, fish, shells, amphibians, etc.). In addition, high temperatures promote the proliferation and growth of bacteria and other microorganisms.

- pH: Natural waters have pH values ranging between 4 and 9. Legislation sets the permitted limits for pH in the 6.5–8.5 range for drinking water. Natural fresh water has a slightly alkaline pH because of the presence of carbonate and bicarbonate ions. Because of agriculture drainage, pH affects the nitrogen and phosphorus release of the deposit sediment [17] and influences the eutrophication phenomenon in water bodies like rivers and lakes. This parameter has a great importance for water environments [18].
- DO: Dissolved oxygen plays a key role in aquatic ecosystems. Most life forms need oxygen to survive. The water receiver has the ability to maintain a maximum dissolved oxygen concentration, called the saturation concentration. Decreasing the concentration of dissolved oxygen to levels below the saturation value leads to degradation of the organic matter, while the aquatic lives are significantly affected or even killed.
- Chlorophyll: The knowledge of the chlorophyll concentration in an ecosystem provides useful information for assessing the phytoplankton biomass in a water area, and is an indicator of pollution from eutrophication [11].

2.3. Description of the Fuzzy Estimators and Fuzzy Implications

In classic logic, every proposition has two values: 0 or 1, true or false, holds or does not hold. The true or false of a fuzzy proposition depends on a degree—in contrast to classical logic, which takes values in the close interval [0,1] for the true or false [19,20]. Fuzzy implications use a more general and gradient model instead of classical logic. The main goal of this study was to investigate some of the eutrophication factors using fuzzy implications in the water body of Lake Kastoria. We aimed to select the most suitable implication that best expresses this lake.

More precisely, we used the membership functions of fuzzy estimators based on confidence intervals defined by extending the traditional confidence interval estimation of the mean of a normal distribution to the fuzzy domain; for readers' convenience, we state the following propositions without their proof [21]:

Proposition (non-asymptotic fuzzy mean of normal distribution-large samples). Let $x_1, \ldots, x_n$ be values assumed by our studied data sets, where $n = 48$. Let also $\gamma \in (0,1)$. The membership function of a fuzzy number is:

$$\mu_\gamma(x) = \begin{cases} \frac{2}{1-\gamma}\Phi\left(\frac{x-\overline{x}}{\sigma/\sqrt{n}}\right) - \frac{\gamma}{1-\gamma}, \ \overline{x} - \frac{\sigma}{\sqrt{n}}\Phi^{-1}\left(1-\frac{\gamma}{2}\right) \le x \le \overline{x} \\ \frac{2}{1-\gamma}\Phi\left(\frac{\overline{x}-x}{\sigma/\sqrt{n}}\right) - \frac{\gamma}{1-\gamma}, \ \overline{x} \le x \le \overline{x} + \frac{\sigma}{\sqrt{n}}\Phi^{-1}\left(1-\frac{\gamma}{2}\right) \\ 0, \ otherwise \end{cases}, \tag{1}$$

$${}^{a}\widetilde{\mu}_\gamma = \left[\overline{x} - z_{h(a)}\frac{\sigma}{\sqrt{n}}, \ \overline{x} + z_{h(a)}\frac{\sigma}{\sqrt{n}}\right], \ a \in (0,1], \tag{2}$$

$$Z_{h(a)} = \Phi^{-1}(1 - h(a)), \ h(a) = \left(\frac{1}{2} - \frac{\gamma}{2}\right)\alpha + \frac{\gamma}{2}, \tag{3}$$

where σ is the standard deviation and $\overline{x}$ the mean value, the support of the membership function is exactly the $\gamma = 0.001$ confidence interval for μ, and the $\alpha - cuts$ of this fuzzy number are the closed intervals and Φ denotes the cumulative distribution function of the standard normal distribution. We found the parameter values from the fuzzy numbers defined in (1). In this way, we estimated for every parameter all the truth values ($\alpha - cuts$) that these constructed fuzzy numbers can provide.

Our next step was to use these truth values for the estimation of a number of implications. The implications are a vital point for the prediction model's construction, since they are considered as the rules that express the relations among the abiotic and biotic parameters in ecosystems. The fuzzy symmetric and asymmetric implications [12,13,22] used in this paper are the following:

$$J_{Mamdani}(x, y) = \min\{x, y\}, \tag{4}$$

$$J_{Larsen}(x, y) = x \cdot y, \tag{5}$$

$$J_{Zadeh}(x, y) = \max(\min\{x, y\}, 1 - x), \tag{6}$$

$$J_{Reichenbach}(x, y) = 1 - x + x \cdot y, \tag{7}$$

$$J_{Luckasiewicz}(x, y) = \min(1 - x + y, 1), \tag{8}$$

$$J(x, y) = \frac{1 - x + y(1 + \lambda x) - y(1 - x)}{1 + \lambda x}, \ \lambda > -1. \tag{9}$$

For the last implication above, the t-norm (Probor) was used [22], while for this research we took $\lambda = -0.99$ [12].

3. Results

Our first step was the construction of the non-asymptotic fuzzy numbers. Figure 2 shows the form of the fuzzy numbers constructed based on confidence intervals defined by extending the traditional confidence interval estimation of the mean of a normal distribution to the fuzzy domain. At this point, it should be mentioned that the mean values of the experimental data correspond to the peak of the following fuzzy numbers. In this method, it is considered that the mean value is the "absolute right" value of every data set, and therefore this value corresponds to the unit. For this application, we also considered water temperature, pH, and dissolved oxygen as independent variables, while the value of chlorophyll was a dependent factor. Below we state the computed membership functions of the constructed fuzzy numbers along with their depiction in Figure 2.

a. $$\mu_{\gamma}{}^{(temp)}(x) = \begin{cases} 2.002\Phi(x/1.097 - 13.7) - 10^{-3}, \ 11.41 \le x \le 15.04 \\ 2.002\Phi(-x/1.097 + 13.7) - 10^{-3}, \ 15.04 \le x \le 18.7 \\ 0, \ otherwise \end{cases}$$

b. $$\mu_{\gamma}{}^{(DO)}(x) = \begin{cases} 2.002\Phi(x/0.3 - 25.5) - 10^{-3}, 6.68 \le x \le 7.68 \\ 2.002\Phi(-x/0.3 + 25.5) - 10^{-3}, 7.68 \le x \le 8.67 \\ 0, \ otherwise \end{cases}$$

c. $$\mu_{\gamma}{}^{(pH)}(x) = \begin{cases} 2.002\Phi(x/0.031 - 268.71) - 10^{-3}, 8.26 \le x \le 8.36 \\ 2.002\Phi(-x/0.031 + 268.71) - 10^{-3}, 8.36 \le x \le 8.47 \\ 0, \ otherwise \end{cases}$$

d. $$\mu_{\gamma}{}^{(Chl)}(x) = \begin{cases} 2.002\Phi(x/0.99 - 9.75) - 10^{-3}, 6.4 \le x \le 9.67 \\ 2.002\Phi(-x/0.99 + 9.75) - 10^{-3}, 9.67 \le x \le 12.95 \\ 0, \ otherwise \end{cases}$$

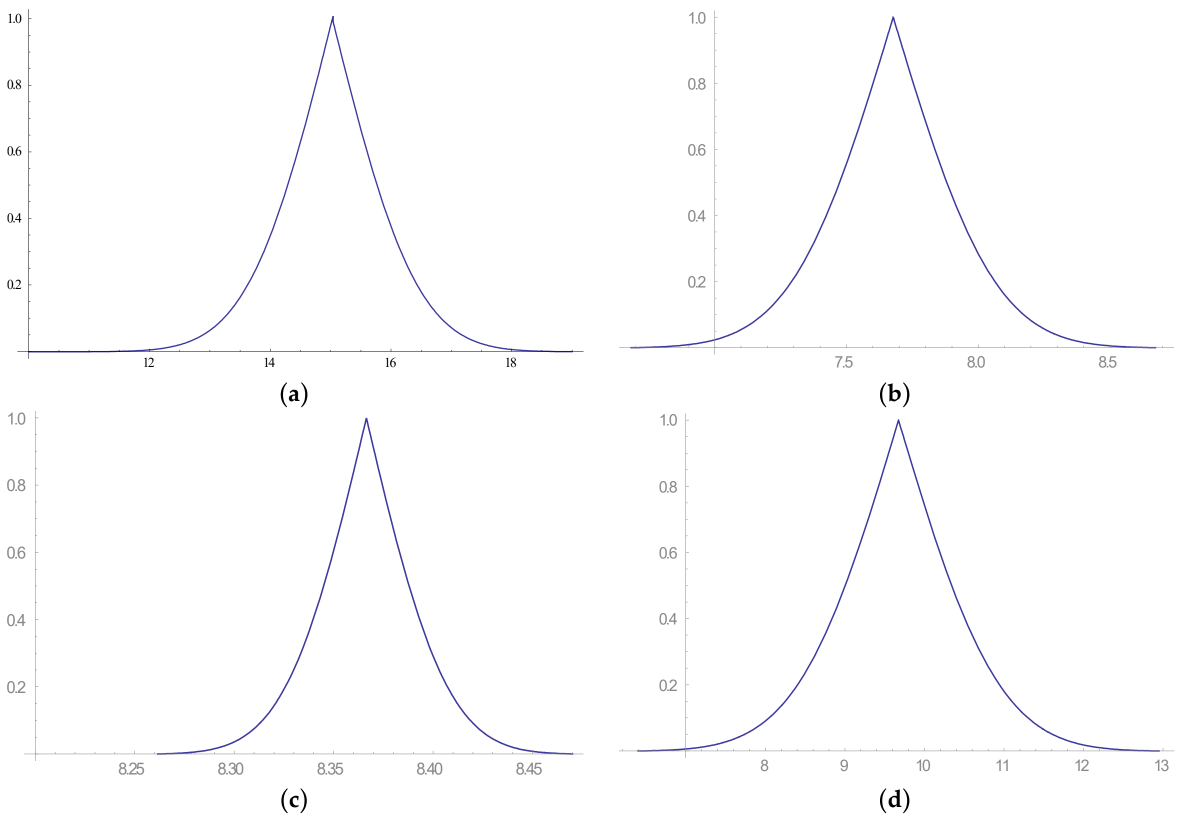

Figure 2. Non-asymptotic fuzzy numbers of the examined factors. (**a**) Water temperature (temp); (**b**) Dissolved oxygen (DO); (**c**) pH; (**d**) Chlorophyll (chl).

After computing all the fuzzy numbers representing the relation between the independents (water temperature, DO, and pH) and the dependent variable (chlorophyll), we estimated the deviations of all the studied implications given by the following relation [12]:

$$\sigma_{p,i} = \sqrt{\left(1-\mu_{p,i}{}^{(1)}\right)^2 + \left(1-\mu_{p,i}{}^{(2)}\right)^2 + \ldots + \left(1-\mu_{p,i}{}^{(j_p)}\right)^2}, \quad (10)$$

where:

μ : the true values of the corresponding implications
p = 1, 2, and 3: the examined independent parameters (water temperature, DO, pH);
i = 1, 2, 3, 4, 5, and 6: the implications (Mamdani, Larsen, Zadeh, Lukasiewicz, Reichenbach, Probor);
j_p : the number of true values.

For readers' convenience, below we state a numerical example:

Let us consider the relationship between the DO and chlorophyll. If the value of DO is 7.4 mg/L and chlorophyll is 9.615 mg/L, then from Figure 2 we take the following implication:

$$7.4 \Rightarrow 9.615,$$

which means that equals to the following relationship estimating the true values:

$$0.35 \Rightarrow 0.95.$$

At this point, we estimate the true value of this implication by the relation of Mamdani:

$$\mu_{2,1} = J_{\text{Mamdani}}(x, y) = \min\{x,\ y\} = \min\{0.35, 0.95\} = 0.35.$$

We followed the same procedure for the rest data sets for all of our studied couples of independent–dependent parameters to find the deviation of the implications ($\sigma_{p,i}$).

The smaller the deviation of the fuzzy parameter, the more accurate we are about the best implication which expresses our study case. Figure 3 presents the deviation of every independent parameter studied in relation to the dependent one. The method of Probor was the best applied implication. All of the studied parameters had the smallest deviation in the last implication. The case of Probor is special because each user can calibrate the λ variable so that they find the lowest possible deviation. In this way, minimizing the deviation, we also minimize the possible errors in predicting parameters that we are called to investigate. Apart from this method, the implications of Reichenbach, Zadeh, and Lucasiewicz are accurate tools for prediction since their deviations were small enough for almost all parameters.

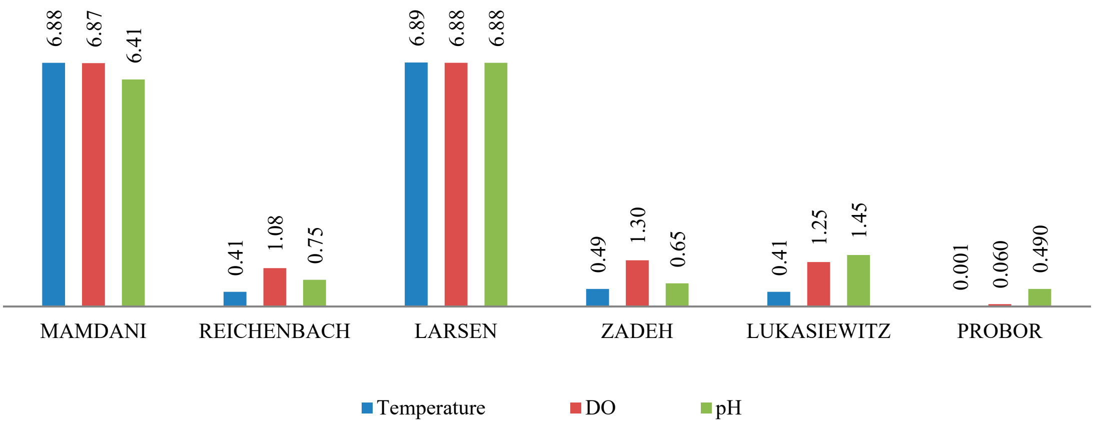

Figure 3. Deviation of the fuzzy parameters influenced by the dependent factor of chlorophyll.

4. Discussion

We obtained similar results to those we obtained in previous papers [12,22] investigating another Mediterranean lake—Lake Karla in Thessaly, which also has a hypertrophic character [16]. We used fuzzy linear regression for the construction of the parameters' fuzzy numbers [21–24] and compared the results with the method of fuzzy estimators. Similarly, we considered that the dependent variable was chlorophyll and all the others were independent. Using the fuzzy linear regression for all the couples of independent–dependent variables, we found all the fuzzy numbers of chlorophyll and consequently the truth values of chlorophyll. Then, we considered that the independent parameter of this ecosystem was chlorophyll. Thus, all the others were the dependent ones. We again applied the method above to estimate all the fuzzy numbers and the truth values that express the water temperature, dissolved oxygen, and pH.

Again applying the fuzzy implications mentioned in Section 2.3, similar results can be observed in Figure 4.

We calculated the true values by applying fuzzy linear regression, and then, using the same implications, we concluded that the implication of Probor was the best for our study case. The smallest deviation was observed in the implications of Probor and Reichenbach. It seems that this method has the advantage of calibrating one parameter (λ) in order to choose the smallest possible value for the studied ecosystem [12]. These fuzzy inference systems have the ability to select the most appropriate implication. Computing the deviation of each implication, it is easy to choose the implication with the smallest deviation. The smaller the deviation is, the more proper the implication for the examined study area.

Having this information about the examined ecosystem, it is easier to understand the mechanisms that influence the trophic state of this water body [25]. The method of fuzzy estimators is an alternative approach in the area of fuzzy logic, and replaces the use of fuzzy linear regression. Prediction models need accuracy in order to have the best solutions in dissemination and exploitation of the results. Monitoring components such as biotic and abiotic parameters is an ideal way to evaluate their effectiveness and their influence on the ecosystem's trophic state. The results are very useful for understanding and determining the correlation of the studied parameters [26]. Having realistic results, the effort for the ecosystem's restoration and protection is of vital importance. This method can be applied across a wide range of research and forecasting software [27,28]. With this mathematical model, we can adapt fuzzy inference systems for the construction of accurate prediction tools for the studied ecosystem. In this way, we obtain a better picture of the trophic state of the lake, having the proper software (i.e., Matlab) for future improvement by monitoring the relations among the parameters.

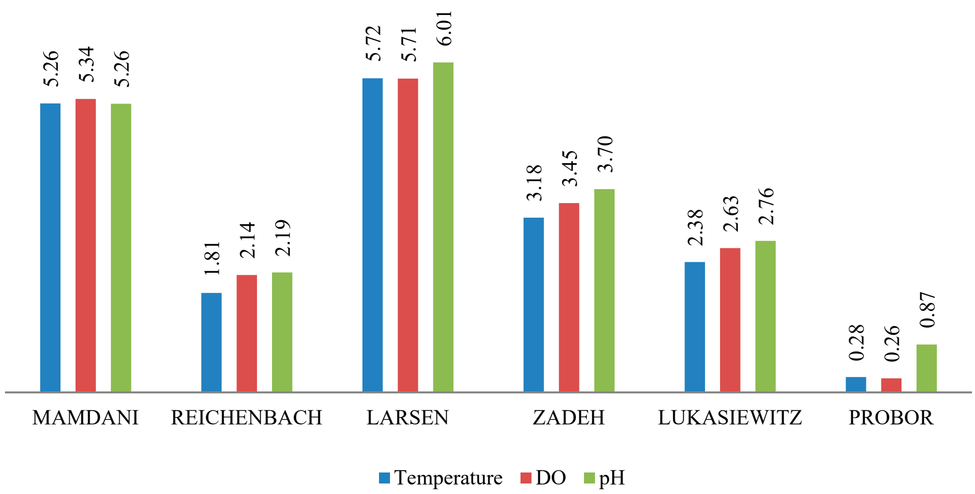

Figure 4. Deviation of the fuzzy parameters constructed by fuzzy linear regression.

5. Conclusions

The waters of Lake Kastoria receive substances due to human activities and natural processes. This results in significant quantities of fertilizers, insecticides, and pesticides being added to the soil each year, with increasing annual rates. Moreover, livestock farming contributes to the production and input of pollutants in the lake. The nutrients resulting from these substances end up in the waters of the lake. Of course, agricultural development and livestock farming cannot be limited, but they must be modernized to help protect the aquatic and terrestrial environment. The effect of water pooling on various nutrients and toxic substances is to create conditions of eutrophication, less water transparency, less dissolved oxygen, and adverse conditions for aquatic organisms—especially fish. Generally, water bodies cope with significant problems. The alternative method of fuzzy logic gives the opportunity to combine many approaches. The method proposed in this paper investigates and selects the most appropriate fuzzy implication using real water quality observations in Lake Kastoria. The use of fuzzy estimators for the construction of the fuzzy numbers is a useful method, and its use is suggested when there is a great deal of data to investigate. Comparing it with the method of fuzzy linear regression, we came to similar results. The implication of Probor was the best option when investigating this ecosystem. By already having the most accurate mathematical relations among parameters, the next step is to create the appropriate software in order to use it as a forecasting tool compared to already known general multi-criteria analysis software.

Author Contributions: B.P., G.P. and G.E. came up with the concept of this research. G.P. and G.E. analyzed the data and used the software. G.E. wrote the paper. B.P. and G.P. supervised the whole research.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

We state the following data, obtained by the department of environmental and water policies of Kastoria:

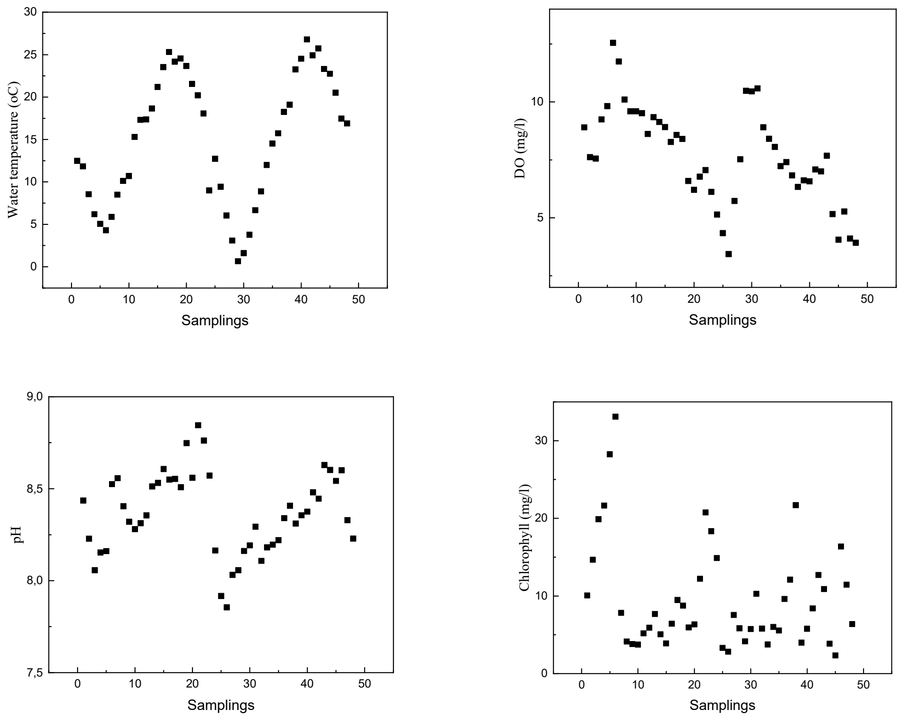

Figure A1. Measurements of the studied parameters of water temperature, dissolved oxygen (DO), pH and chlorophyll, for the years 2015 to 2017 taken every fifteen days.

References

1. Stefanidis, K.; Dimitriou, E. Differentiation in Aquatic Metabolism between Littoral Habitats with Floating-Leaved and Submerged Macrophyte Growth Forms in a Shallow Eutrophic Lake. *Water* **2019**, *11*, 287. [CrossRef]
2. Demertzi, K.; Papadimos, D.; Aschonitis, V.; Papamichail, D. A Simplistic Approach for Assessing Hydroclimatic Vulnerability of Lakes and Reservoirs with Regulated Superficial Outflow. *Hydrology* **2019**, *6*, 61. [CrossRef]
3. Xu, C.; Wang, H.U.; Yu, Q.; Wang, H.Z.; Liang, X.M.; Liu, M.; Jeppesen, E. Effects of Artificial LED Light on the Growth of Three Submerged Macrophyte Species during the Low-Growth Winter Season: Implications for Macrophyte Restoration in Small Eutrophic Lakes. *Water* **2019**, *11*, 1512. [CrossRef]
4. Zheng, T.; Cao, H.; Liu, W.; Xu, J.; Yan, Y.; Lin, X.; Huang, J. Characteristics of Atmospheric Deposition during the Period of Algal Bloom Formation in Urban Water Bodies. *Sustainability* **2019**, *11*, 1703. [CrossRef]
5. Doulgeris, C.; Papadimos, D.; Kapsomenakis, J. Impacts of climate change on the hydrology of two Natura 2000 sites in Northern Greece. *Reg. Environ. Chang.* **2016**, *16*, 1941–1950. [CrossRef]
6. Wang, W.; Lee, X.; Xiao, W.; Liu, S.; Schultz, N.; Wang, Y.; Zhang, M.; Zhao, L. Global lake evaporation accelerated by changes in surface energy allocation in a warmer climate. *Nat. Geosci.* **2018**, *11*, 410–414. [CrossRef]
7. IPCC. Summary for policymakers. In *Climate Chang. 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013.
8. Leon-Munoz, J.; Echeverria, C.; Marce, R.; Riss, W.; Sherman, B.; Iriarte, J.L. The combined impact of land use change and aquaculture on sediment and water environmental quality in oligotrophic Lake Rupanco. *J. Environ. Manag.* **2013**, *128*, 283–291. [CrossRef]

9. Lin, B.; Chen, X.; Yao, H.; Chen, Y.; Liu, M.; Gao, L.; James, A. Analyses of land use change impacts on catchment runoff using different time indicators based on SWAT model. *Ecol. Indic.* **2015**, *58*, 55–63. [CrossRef]
10. Matzafleri, N.; Psilovikos, A.; Neofytou, C.; Kagalou, I. Determination of the Trophic Status of Lake Kastoria, Western Macedonia, Greece. In Proceedings of the Small and decentralised water and wastewater treatment plants IV, Volos, Greece, 25–27 October 2013; ISBN 978-960-6865-72-5.
11. Richardson, K.; Jørgensen, B.B. *Eutrophication in a Coastal Marine Ecosystem*; Coastal and estuarine studies; American Geophysical Union: Washington, DC, USA, 1996; Volume 1, pp. 1–9.
12. Ellina, G.; Papaschinopoulos, G.; Papadopoulos, B.K. Fuzzy inference systems: Selection of the most appropriate fuzzy implication in terms of statistical data. *Environ. Process.* **2017**, *4*, 923–935. [CrossRef]
13. Botzoris, G.; Papadopoulos, K.; Papadopoulos, B.K. A method for the evaluation and selection of an appropriate fuzzy implication by using statistical data. *Fuzzy Econ. Rev.* **2015**, *XX*, 19–29. [CrossRef]
14. Ellina, G.; Papaschinopoulos, G.; Papadopoulos, B.K. Research of Fuzzy Implications via Fuzzy Linear Regression in Data Analysis for a Fuzzy Model. *J. Comput. Methods Sci. Eng.* **2019**. accepted for publication.
15. Moustaka-Gouni, M.; Vardaka, E.; Michaloudi, E.; Kormas, K.A.; Tryfon, E.; Mihalatou, H.; Gkelis, S.; Lanaras, T. Plankton food web structure in a eutrophic polymictic lake with a history in toxic cyanobacterial blooms. *Limnol. Oceanogr.* **2006**, *51*, 715–727. [CrossRef]
16. Ellina, G.; Kagalou, I. Selection of the most appropriate parameter for the chlorophyll-a estimation of an artificial lake via fuzzy linear regression. *Eur. Water* **2016**, *55*, 105–114.
17. Tao, Y.; Wang, S.; Guan, X.; Xu, D.; Chen, H.; Ji, M. Study on Characteristics of Nitrogen and Phosphorus Loss under an Improved Subsurface Drainage. *Water* **2019**, *11*, 1467. [CrossRef]
18. Fisher, L.H. *Effect of Water-Column pH on Sediment-Phosphorus Release Rates in Upper Klamath Lake, Oregon, 2001*; U.S. Geological Survey: Reston, VA, USA, 2004.
19. Profillidis, V.A.; Papadopoulos, B.K.; Botzoris, G.N. Similarities in fuzzy regression models and application on transportation. *Fuzzy Econ. Rev.* **1999**, *4*, 83–98. [CrossRef]
20. Papadopoulos, B.; Tsagarakis, K.P.; Yannopoulos, A. Cost and land functions for wastewater treatment projects: Typical simple linear regression versus fuzzy linear regression. *J. Environ. Eng.* **2007**, *133*, 581–586. [CrossRef]
21. Sfiris, D.S.; Papadopoulos, B.K. Non-asymptotic fuzzy estimators based on confidence intervals. *Inf. Sci.* **2014**, *279*, 446–459. [CrossRef]
22. Ellina, G.; Papaschinopoulos, G.; Papadopoulos, B.K. Research of Fuzzy Implications via Fuzzy Linear Regression in a Eutrophic Waterbody. In *AIP Conference Proceedings 1978*; AIP Publishing: New York, NY, USA, 2018; p. 290007. [CrossRef]
23. Papadopoulos, B.K.; Sirpi, M.A. Similarities in fuzzy regression models. *J. Optim. Theory Appl.* **1999**, *102*, 373–383. [CrossRef]
24. Chrysafis, K.A.; Papadopoulos, B.K. Cost–volume–profit analysis under uncertainty: A model with fuzzy estimators based on confidence intervals. *Int. J. Prod. Res.* **2008**, *47*, 5977–5999. [CrossRef]
25. Brito, D.; Neves, R.; Branco, M.A.; Prazeres, A.; Rodrigues, S.; Maria, C.; Gonçalves, M.C.; Ramos, T.B. Assessing Water and Nutrient Long-Term Dynamics and Loads in the Enxoé Temporary River Basin (Southeast Portugal). *Water* **2019**, *11*, 354. [CrossRef]
26. Buriboev, A.; Kang, H.K.; Ko, M.C.; Oh, R.; Abduvaitov, A.; Jeon, H.S. Application of Fuzzy Logic for Problems of Evaluating States of a Computing System. *Appl. Sci.* **2019**, *9*, 3021. [CrossRef]
27. Pagouropoulos, P.; Tzimopoulos, C.; Papadopoulos, B. Selecting the most appropriate fuzzy implication based on statistical data. *Int. J. Fuzzy Syst. Adv. Appl.* **2016**, *3*, 32–42.
28. Pagouropoulos, P.; Tzimopoulos, C.; Papadopoulos, B. A Method for the Detection of the Most Suitable Fuzzy Implication for Data Applications. In *Engineering Applications of Neural Networks, Communications in Computer and Information Science*; Springer: Heidelberg, Germany, 2017; Volume 744, pp. 242–255.