Surface Water Quality Assessment on a Wetland in Peru Using Grey Systems

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***Abstract*—Coastal wetlands play a fundamental role, as they give diverse ecosystem services to humanity. However, due to anthropic activities that take place in the coastal region, large areas of wetlands are being lost. A case in Peru is the Pantanos de Villa, a coastal wetland located in the district of Chorrillos and which after several years today represents an area of 263.27 hectares. In Peru, there are regulations and water quality indices, but there is not one specifically for wetlands. This work aims to propose a wetland water quality index based on international standards that have been used in the evaluation of water quality of wetlands, whose parameters adopted from these standards are dissolved oxygen, electrical conductivity, pH, nitrates, total phosphorus and total dissolved solids. The grey clustering method, which is based on grey systems, was used, as this method allows knowing and systemically understanding the behavior of the wetland. The index was applied to assess water quality of the Mayor, Genesis and Marvilla lagoons of Pantanos de Villa. The experimental data was obtained from the results of the monitoring carried out by the Municipal Authority of Pantanos de Villa from September 2020 to March 2021. The results showed that the three lagoons present a level of severe contamination.**

***Index Terms*—grey-systems, water-quality, wetland, surface-water.**

I. Introduction

WETLANDS are important natural resources, called "the cradle of life" and "the kidney of the Earth". It has many functions such as providing water sources, protecting biodiversity, regulating the climate [1], removing organic pollutants, providing resources [2] and, being more specific, coastal wetlands play a fundamental role in controlling coastal erosion by regulating floods [3]. They are also large carbon sinks, a capacity that is assimilated to that of the world's forests among other ecosystem services [4]. However, during the 20th and early 21st centuries, large losses of wetlands extensions in general are reported, corresponding between 62 and 63% to coastal wetlands, and part of it due to anthropic activities since in this coastal region the great ones of the country settle [5]. In Peru, a case that exemplifies the decrease in the quality and quantity of the Pantanos de Villa, since 1996 it has been verified that one of the main pollution problems are the detergents used by the population near the reservoir, which, when using the supply channel, as domestic laundries, these pollutants end up in the reservoir lagoons; the discharge of wastewater in the Marvilla lagoon of Pantanos de Villa, as well as, the dumping of solid waste and the presence of excreta from animals that have settled around this area. In addition, in Peru there is no specific legal regulation for wetlands and the studies carried out focused on evaluating the quality of the waters of a reservoir lagoon that have made use of the environmental quality standards for water [6].

One of the most important tools that exists to determine the state of contamination of slow water bodies is the water quality index (WQI), which requires the availability of data on parameters that characterize state of water quality of a natural body, those are Temperature, pH, Dissolved Oxygen, Total Phosphate, nitrates, Total Dissolved Solids (TDS), among others [7]. As a response to this problem, the theory of grey systems developed by Deng emerged, which works with uncertain data sets, with low quality data available or incomplete data [8]. The Grey Clustering method is one of the most useful elements of the Grey Systems Theory, which allows the classification of objects within defined classes [9], [10]. Specifically, the grey clustering method based on the construction of functions (whitenization weight functions) is the most used to verify if certain objects belong to a class, in order to give them a differentiated handling [11], [12]. As demonstrated by Boes T. et. to in 2020, when carrying out the evaluation of the contamination of a body of water with nitrogen through the use of a methodology based on grey clustering and the entropy-weighting method which allows determining the weight of each criterion within the clustering ranges. For this, they developed two grey indices: priority grey index for nitrogen management (GNMP for its acronym in English), used to determine the need to manage nitrogen contamination in water; and the grey index of contamination by land use (GLUP for its acronym in English), which evaluates the anthropogenic pressures that generate contamination with nitrogen by the use of land [13]. Likewise, Linfei, Shiguo and Wanguang, in 2007, in China applied the Grey Clustering methodology to assess the water quality of the Zhalong wetland based on environmental quality standards of surface water, the whitening weight function was used to describe the water quality,the weight was determined and a comprehensive grey mathematical model was constructed and this model was used to analyse the water quality of the Zhalong Wetland [14].

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In this case, as wetland water quality index was not available,it was elaborated based on international regulations whose scope of study is wetlands, among these regulations is the Chinese regulation, Environmental Quality Standards for Surface Water, the Water Quality Classification based on Iranian Environmental Protection Agency (IEPA) and the Water Quality Index, prepared on the basis of the standard procedures proposed by Shah and Joshi [15], prescribed standards for surface water and with due consideration from different standardization agencies such as the Central Board of Pollution Control, the Bureau of Indian Standards (BIS), the Indian Council of Medical Research (ICMR), World Health Organization (WHO), among others [16]. After that, the grey clustering method was applied, which has proven to be a useful method and does not require abundant input information [14], [17].

This work focuses on Pantanos de Villa, a wetland located on the Peruvian coast, south of the urban area of Lima, which concentrates and harbors an important and significant biological diversity, which is why it is recognized as a important site. This reservoir is made up of several lagoons: the Mayor lagoon, Genesis lagoon, ANAP lagoon, Marvilla lagoon, Las Garzas lagoon, La Pampa lagoon; two main channels that supply water to the entire wetland, an outcrop and swampy areas [18].

In this sense, the objectives of this study are to propose a comprehensive water quality assessment index for wetlands and to apply the proposed index to a case study in Peru: Pantanos de Villa.

II. Methodology

In this Section details of the methodology are presented.

A. The grey clustering method

The application of the grey clustering method, which is based on grey systems, was performed by the steps of Center-point Triangular Whitenization Functions (CTWF), as shown in Fig. 1.

1) Step 1: Determine the object numbers, criteria, and grey classes:

First, we define n as the number of criteria ($j = 1, 2 \ldots n$), m objects ($i = 1, 2 \ldots m$), which, are defined to be classified into z classes ($K = 1, 2 \ldots z$). Then, the central points were identified $\lambda(1), \lambda(2), \lambda(3) \ldots \lambda(z)$ of these classes.

2) Step 2: Non-dimensioning:

Due to the degree of disparity between the magnitude and the significance between the parameters, the monitoring data was dimensioned, in order to provide uniform values for the calculation by the grey clustering method.

3) Step 3: Determination of the triangular functions and their values:

The grey classes are expanded in the directions of each parameter and for this the parameters of both regulations, which provide the data to measure quality, was used as a reference. With which, according to the number of quality levels for each parameter, the number of functions for each parameter was determined. A graphic representation is shown in Fig. 2.

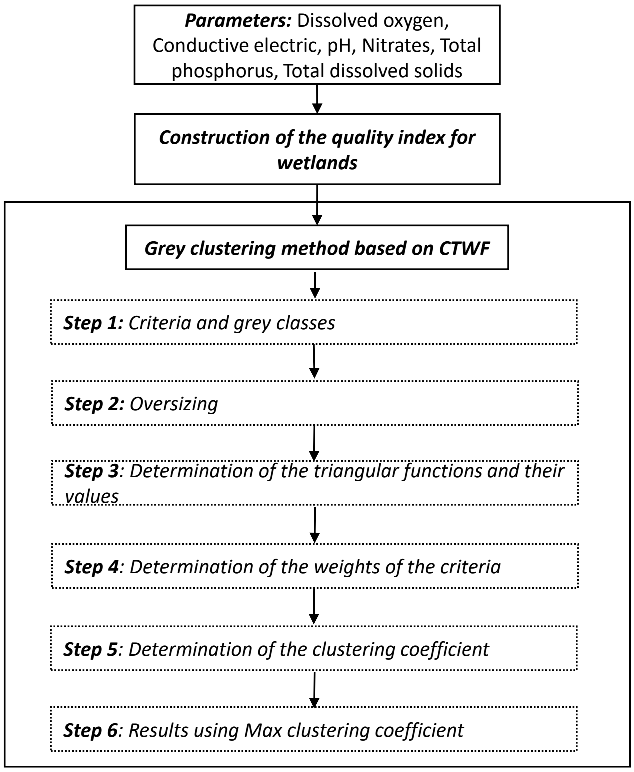

Fig. 1. Grey clustering procedure.

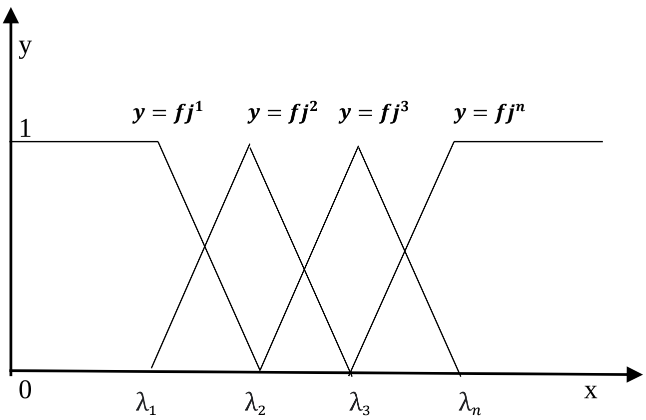

Fig. 2. CTWF graphic representation.

The correspondence rule for triangular functions is presented in Equation 1 and 2.

$$f_j^k(x_{ij}) = \begin{cases} 1 & x \in [0,\ \lambda_1] \\ \frac{\lambda_2 - x}{\lambda_2 - \lambda_1} & x \in [\lambda_1,\ \lambda_2] \\ 0 & x \in [\lambda_2,\ \infty] \end{cases} \quad (1)$$

$$f_j^{c(c\neq k,1)}(x_{ij}) = \begin{cases} \frac{x - \lambda_2}{\lambda_3 - \lambda_2} & x \in [\lambda_2,\ \lambda_3] \\ \frac{\lambda_n - x}{\lambda_n - \lambda_3} & x \in [\lambda_3,\ \lambda_n] \\ 0 & x \notin [\lambda_2, \lambda_n] \end{cases} \quad (2)$$

4) Step 4: Determine the weights of the criteria:

This step is added to the revised methodology as it provides an objective criterion for the weighting of the clustering vector. It is calculated according to the harmonic mean of the central data of the grey classes by Equation 3.

$$n_j^k = \frac{\frac{1}{\lambda_j^k}}{\sum_{j=1}^{s} \lambda_j^k} \tag{3}$$

5) Step 5: Determine the clustering coefficient:

Determination of the clustering vector for objects i, $i = 1, 2 \ldots m$, in the grey classes k,$k = 1, 2 \ldots s$, of the parameter $j = 1, 2 \ldots n$, for a monitoring value of water, it is defined by Equation 4.

$$\sigma_j^k = \sum_{j=1}^{n} f_j^k (x_{ij}) .n_j \tag{4}$$

6) Step 6: Results using maximum clustering coefficient:

If $max_{1<k<s}\{\sigma_i^k\}$ we decide that objects i belong to the grey class k^*. When there are some objects in grey classes k^*, these objects can be ordered according to the magnitudes of their clustering coefficient.

III. Case study

The analysis of the surface water quality was carried out in the Genesis Lagoon, Mayor Lagoon and Marvilla Lagoon, which are 3 bodies of water belonging to Pantanos de Villa, a coastal wetland that originates from the outcrop of groundwater from the aquifer located in the lower part of the Rímac-Lurín inter-basin [19], in the district of Chorrillos, within the city of Lima, Peru with an area of 263.27 hectares as shown in Fig. 3.

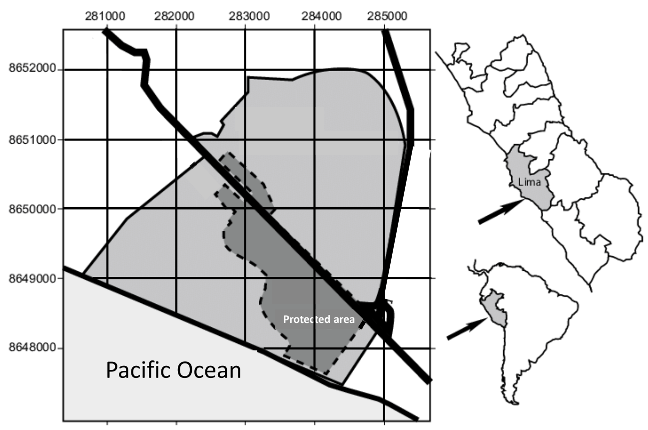

Fig. 3. Pantanos de Villa, Peru.

Now, the steps of the grey clustering method was applied:

A. Step 1: Determine the object numbers, criteria, and grey classes

1) Study Objects: these were formed by three lagoons from Pantanos de Villa, Peru.

G1= Genesis Lagoon
G2= Marvilla Lagoon
G3= Mayor Lagoon

2) Criteria: these were formed by following parameters.

C1= Hydrogenionic potential (pH)
C2= Oxygen demand (OD) (mg/l)
C3= Nitrates (mg/l)
C4= Total phosphorus (mg/l)
C5= Total dissolved solids (TDS) (mg/l)
C6= Electric conductivity (EC) (s/cm)u

2) Grey classes: these were formed by following quality levels.

S1= Class I (Clean) : λ_1
S2= Class II (Slight) : λ_2
S3= Class III (Moderate) : λ_3
S4= Class IV (Excess) : λ_4
S5= Class V (Severe) : λ_5

According to water law for wetlands [15], [16], the values to grey classes for each parameter are presented in Table I.

TABLE I
GREY CLASSES FOR WATER QUALITY OF WETLANDS

Criteria	S1	S2	S3	S4	S5
C1	7.75	6.85	6.75	6.60	6.45
C2	6.55	5.55	4.55	3.55	2.55
C3	12.00	22.50	33.00	43.00	55.00
C4	0.02	0.05	0.10	0.20	0.40
C5	500	1500	2100	3000	3800
C6	375	1125	1875	2625	3000

Data was obtained from institutions of Peru government [20]. The values are presented in Table II.

TABLE II
DATA OBTAINED FOR EACH CRITERION

Criteria	G1	G2	G3
C1	8.01	9.43	7.65
C2	7.29	11.32	12.05
C3	11.54	44.91	12.00
C4	0.05	0.41	0.19
C5	5690.42	4743.33	7045.00
C6	0.75	0.75	0.75

B. Step 2: Non-dimensioning

The values of Table I and II were Non-dimensioned using the arithmetic mean, the results are presented in Table III and IV.

TABLE III
STANDARD VALUES NON-DIMENSIONING

Criteria	S1	S2	S3	S4	S5
C1	1.126	0.996	0.981	0.959	0.938
C2	1.440	1.220	1.000	0.780	0.560
C3	0.363	0.680	0.997	1.299	1.662
C4	0.130	0.325	0.649	1.299	2.597
C5	0.208	0.625	1.042	1.458	1.667
C6	0.229	0.688	0.963	1.376	1.743

TABLE IV
SAMPLING DATA NON-DIMENSIONING

Criteria	G1	G2	G3
C1	1,165	1,371	1,113
C2	1,603	2,487	2,648
C3	0.349	1,357	0.363
C4	0.314	2,656	1,218
C5	3,161	2,635	3,914
C6	0.000	0.000	0.000

C. Step 3: Determination of the triangular functions and their values

Replacing the values of Table III in Equation 2, the triangular functions of the five grey classes were obtained for each parameter. Next, the functions of first criterion (C1) corresponding to the hydrogen potential are presented; in the same way was carried out for each criterion as shown in Equations 5 – 9.

$$f_1^1(x_{ij}) = \begin{cases} 1 & x \in [0,\ 0.938] \\ \frac{0.959-x}{0.021} & x \in [0.938,\ 0.959] \\ 0 & x \in [0.959,\ \infty] \end{cases} \tag{5}$$

$$f_1^2(x_{ij}) = \begin{cases} 0 & x \notin [0.938,\ 0.981] \\ \frac{x-0.938}{0.021} & x \in [0.938,\ 0.959] \\ \frac{0.981-x}{0.022} & x \in [0.959,\ 0.981] \end{cases} \tag{6}$$

$$f_1^3(x_{ij}) = \begin{cases} 0 & x \notin [0.959,\ 0.996] \\ \frac{x-0.959}{0.022} & x \in [0.959,\ 0.981] \\ \frac{0.996-x}{0.015} & x \in [0.981,\ 0.996] \end{cases} \tag{7}$$

$$f_1^4(x_{ij}) = \begin{cases} 0 & x \notin [0.981,\ 1.126] \\ \frac{x-0.981}{0.015} & x \in [0.981,\ 0.996] \\ \frac{1.126-x}{0.13} & x \in [0.996,\ 1.126] \end{cases} \tag{8}$$

$$f_1^5(x_{ij}) = \begin{cases} 0 & x \notin [0,\ 0.996] \\ \frac{x-0.996}{0.013} & x \in [0.996,\ 1.126] \\ 1 & x \in [1.126,\ \infty] \end{cases} \tag{9}$$

D. Step 4: Determine the weights of the criteria

Replacing the values of Table III in Equation 4, the weights of each criterion were obtained, which are shown in Table V.

E. Step 5: Determine the clustering coefficient

As a example for C1 criterion, the values from VI were replaced in Equations 5 - 9. these results were multiplied by their weight corresponding. The clustering coefficients result are present in Table VI.

TABLE V
WEIGHTS OF EACH CRITERION

Criteria	S1	S2	S3	S4	S5
C1	0.042	0.107	0.155	0.198	0.213
C2	0.033	0.087	0.152	0.243	0.356
C3	0.130	0.156	0.153	0.146	0.120
C4	0.363	0.327	0.235	0.146	0.077
C5	0.226	0.170	0.146	0.130	0.120
C6	0.206	0.154	0.158	0.138	0.114

TABLE VI
CLUSTERING COEFFICIENTS OF G1 OBJECT

Criteria	C1	C2	C3	C4	C5	C6	Outcome
f1 (X)	0	0	1	0.055	0	1	0.356
f2 (X)	0	0	0	0.945	0	0	0.309
f3 (X)	0	0	0	0	0	0	0.000
f4 (X)	0	0	0	0	0	0	0.000
f5 (X)	1	1	0	0	1	0	0.689

F. Step 6: Results using maximum clustering coefficient

In same way, results for all criteria and objects were obtained. Then, the highest clustering coefficient was selected according to each object, thus obtaining the maximum clustering coefficients. The result are presented in Table VII.

TABLE VII
MAXIMUM CLUSTERING COEFFICIENT OF EACH GROUP

Obj	S1	S2	S3	S4	S5	Max	Class
G1	0.356	0.309	0.000	0.000	0.689	0.689	Severe
G2	0.206	0.000	0.000	0.123	0.785	0.785	Severe
G3	0.336	0.000	0.029	0.148	0.667	0.667	Severe

IV. RESULTS AND DISCUSSION

In this Section results and discussion are presented according to objectives of this work.

First, from Fig. 4, constructed from Table VII, shows the results for three lagoons(objects), which have a severe level of pollution. In addition, the evaluation of water quality of the three lagoons allows us to do a hierarchy according to the water quality index for wetlands proposed in this work, a relationship of high to lower water quality is shown as follows:

Marvilla lagoon > Genesis lagoon > Mayor lagoon

Second, according to this we could obtain that the lagoon with the greatest water contamination in Pantanos de Villa for the period between the months of September 2020 and March 2021 is Marvilla lagoon and the least contaminated is Mayor lagoon. This severe contamination is possibly due to the presence of industries adjacent to the water supply channels to the swamps, where the lack wastewater treatment would directly affect the canal of wetlands [21].

Third, in the case of Laguna Marvilla, the information obtained for the month of September 2020, in two stations, the highest peaks of the nitrate parameter were obtained with an average value of 107.7 mg/L, five times higher than the classification I standard value (20 mg/L). This parameter has the most homogeneous distribution of weighting; therefore, it

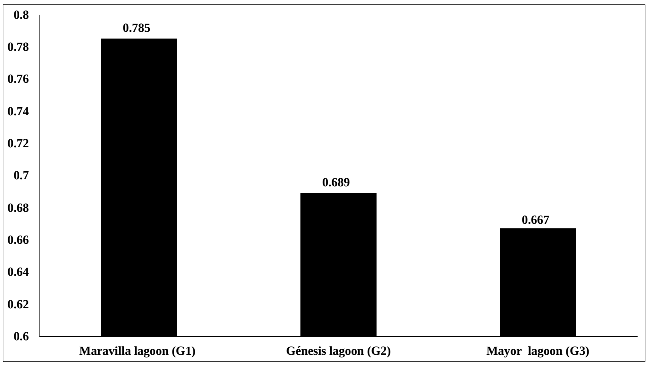

Fig. 4. Max clustering coefficient for each lagoon.

is the one that has the greatest influence within the result. In addition, nitrates in surface and groundwater are derived from the natural decomposition, by microorganisms, of organic nitrogenous materials such as the proteins of plants, animals and animal excreta [22], [23]. Regarding degradation in the natural environment, it is estimated that nitrates can be maintained in groundwater for a period of between 1 to 150 years [24], [25].

V. Conclusion

The water quality assessment, based on the grey clustering method, for wetlands allowed us to propose a methodology for the comprehensive evaluation of the quality of three lagoons contained in Pantanos de Villa, Peru. The quality of the water in the lagoons Mayor, Genesis and Marvilla presented a quality categorized in a linguistic classification of “severe” belonging to class V. Likewise, with the categorization obtained, it is now easier to communicate to the community about the status of the quality of water bodies, as opposed to the presentation of the monitoring data used as an input, which makes it difficult to understand the quality status.

Based on this work, water quality evolution assessment in the study area can be developed in the future, once the pandemic season ends and with the communication of results future monitoring campaigns, it will be possible to work in the same way in order to obtain tools for evaluating water quality and making a respective comparison between the pandemic and the natural quality of the reservoir. Likewise, the presented methodology can be applied to other projects in general considering the evaluation and/or inclusion of the parameters contained in the proposed quality index. In addition, it is recommended to carry out an environmental evaluation in order to identify the polluting sources with precision and give adequate follow-up and to have control of the water quality of the wetland, it is recommended to carry out monitoring monthly considering the six parameters that constitute the Prohvilla Authority from Peru.

References

[1] X. tao Li, S. Huang, J. ren Li, M. Xu, and X. Song, “The study of wetlands change in yellow river delta based on rs and gis,” in *2007 IEEE International Geoscience and Remote Sensing Symposium*, 2007, pp. 4607–4610.

[2] Z. Zhenfei, “Wetland environmental protection and spatial distribution of plant communities in arid and semi-arid areas of northwest china,” in *2019 8th International Conference on Agro-Geoinformatics (Agro-Geoinformatics)*, 2019, pp. 12–16.

[3] Y. Chen, X. Li, and M. Min, “Mapping for terrestrial ecosystem services: a review,” in *2019 8th International Conference on Agro-Geoinformatics (Agro-Geoinformatics)*, 2019, pp. 23–28.

[4] J. Yin, M. Xi, S. Deng, S. Tan, J. Chen, Y. Wei, Z. Wu, and S. Dustdar, “A service pattern-oriented computing architecture for service ecosystems,” *IEEE Internet Computing*, vol. 26, no. 1, pp. 51–59, 2022.

[5] F. Falcini, V. E. Brando, D. Ciani, S. Colella, J. A. Concha, E. Organelli, J. Pitarch, G. Volpe, F. Braga, G. M. Scarpa, C. Giardino, and M. Rio, “Satellite based analyses on potential effects of the covid19 lockdown over coastal areas: The esa-race soon project,” in *2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS*, 2021, pp. 7516–7519.

[6] S. K. Srivastava and S. Devaiya, “Error of approximation of functions, conjugate to the functions belonging to weighted lipschitz class using matrix means,” *IAENG International Journal of Applied Mathematics*, vol. 51, no. 4, pp. 837–841, 2021.

[7] X. X. Romeiko, Z. Guo, and Y. Pang, “Comparison of support vector machine and gradient boosting regression tree for predicting spatially explicit life cycle global warming and eutrophication impacts: A case study in corn production,” in *2019 IEEE International Conference on Big Data (Big Data)*, 2019, pp. 3277–3284.

[8] S. Liu, C. Lin, and Y. Yang, “Several problems need to be studied in grey system theory,” in *2017 International Conference on Grey Systems and Intelligent Services (GSIS)*, 2017, pp. 63–66.

[9] A. Delgado and I. Romero, “Environmental conflict analysis on a hydrocarbon exploration project using the shannon entropy,” in *Proceedings of the 2017 Electronic Congress, E-CON UNI 2017*, vol. 2018-January, 2017, pp. 92–95.

[10] A. Delgado, A. Aguirre, E. Palomino, and G. Salazar, “Applying triangular whitenization weight functions to assess water quality of main affluents of rimac river,” in *Proceedings of the 2017 Electronic Congress, E-CON UNI 2017*, vol. 2018-January, 2017, pp. 105–108.

[11] A. Delgado and I. Romero, “Applying the grey systems theory to assess social impact from an energy project,” in *2018 IEEE XXV International Conference on Electronics, Electrical Engineering and Computing (INTERCON)*, 2018, pp. 78–81.

[12] A. Delgado, P. Montellanos, and J. Llave, “Air quality level assessment in lima city using the grey clustering method,” in *2018 IEEE International Conference on Automation/XXIII Congress of the Chilean Association of Automatic Control (ICA-ACCA)*, 2018, pp. 123–126.

[13] “Using grey clustering to evaluate nitrogen pollution in estuaries with limited data,” *Science of The Total Environment*, vol. 722, p. 137964, 2020.

[14] “Application of grey clustering method in eutrophication assessment of wetland,” *Journal of American Science*, vol. 4, pp. 53–58, 2007.

[15] F. B. Semiromi, A. H. Hassani, A. Torabian, A. R. Karbassi, and F. H. Lotfi, “Water quality index development using fuzzy logic: A case study of the Karoon River of Iran,” *1.*, vol. 10, no. 50, pp. 10 125–10 133, 2011.

[16] A. K. Singh, M. Sathya, S. Verma, and S. Jayakumar, “Spatiotemporal variation of water quality index in Kanwar wetland, Begusarai, India,” *Sustain. Water Resour. Manag.*, vol. 6, no. 3, pp. 44–52, Jun. 2020.

[17] W. S. Fang, S. Karim, M. S. A. Mohamad, R. Loxton, and R. Volker, “On the Modification of the Discrete Filled Function Algorithm for Nonlinear Discrete Optimization,” *IAENG Int. J. Appl. Math.*, vol. 51, no. 4, pp. 930–935, 2021.

[18] D. L. N. Yesquen, K. K. L. Ayala, C. A. C. Olivera, J. L. J. Nakayo, J. W. V. Flores, and E. R. E. Farfán, “Impact of climate variability on the ecological components of a swamp: The case of pantanos de villa, peru,” *Chem. Eng. Trans.*, vol. 86, pp. 493–498, 2021.

[19] E. Benites-Alfaro, Z. del Pilar Tito Quispe, J. J. Nakayo, E. A. Suasnabar, V. T. Mendivil, E. E. Farfán, and C. Rodriguez, “Trophic status index of the waters of the Pantanos de Villa Protected Natural Reserve, Chorrillos, PerÚ,” *J. Crit. Rev.*, vol. 7, no. 19, pp. 447–453, 2020.

[20] “MONITOREO DE PARÁMETROS FISICOQUÍMICOS PANTANOS DE VILLA 2020 III · Portal de Datos Abiertos - Municipalidad Metropolitana de Lima,” Apr. 2022, [Online; accessed 20. Apr. 2022]. [Online]. Available: https://datosabiertos.munlima.gob.pe/dataviews/257094/monitoreo-de-parametros-fisicoquimicos-pantanos-de-villa-2020-iii

[21] A. H. Sánchez Sánchez, “Restauración de los canales eutrofizados de abastecimiento de agua a los Pantanos de Villa,” Ph.D. dissertation, Pontificia Universidad Católica del Perú, Nov. 2020. [Online]. Available: https://tesis.pucp.edu.pe/repositorio/handle/20.500.12404/17439

[22] S. Mishra, S. Suresh, M. S. Chauhan, V. Subbaramaiah, and V. Gosu, “Recent Progress in Carbonaceous Materials for the Nitrate Adsorption,” *J. Hazard. Toxic Radioact. Waste*, vol. 26, no. 3, p. 04022013, Jul. 2022.

[23] B. Malecka, A. Lacz, E. Drozdz, and A. Malecki, “Thermal decomposition of d-metal nitrates supported on alumina,” *J. Therm. Anal. Calorim.*, vol. 119, no. 2, pp. 1053–1061, Feb. 2015.

[24] J. N. Weitzman, J. R. Brooks, J. E. Compton, B. R. Faulkner, P. M. Mayer, R. E. Peachey, W. D. Rugh, R. A. Coulombe, B. Hatteberg, and S. R. Hutchins, “Deep soil nitrogen storage slows nitrate leaching through the vadose zone,” *Agric. Ecosyst. Environ.*, vol. 332, p. 107949, Jul. 2022.

[25] J. W. Park, S. M. Thomas, A. N. Schechter, and B. Piknova, “Control of rat muscle nitrate levels after perturbation of steady state dietary nitrate intake,” *Nitric Oxide Biol. Chem.*, vol. 109-110, pp. 42–49, May 2021.