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Water Index Analysis of the San José River, Tegucigalpa, Honduras

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Abstract* – Water, which covers most of the Earth, is a fundamental resource for sustaining life. Although most organisms live in terrestrial environments, the interaction between aquatic and terrestrial ecosystems remains crucial. Riparian zones, in particular, provide essential habitats for unique species and facilitate key ecological processes. Water quality is a determining factor for the health of these ecosystems, and its deterioration can seriously affect biodiversity and compromise long-term sustainability.The analysis of water quality in the San José River, in Tegucigalpa, is vital due to its influence on local communities and nearby watersheds. Using statistical tools and Design of Experiments, it has been shown that several parameters exceed the maximum values allowed frequently. This poses serious risks to both human health and the environmental balance. Therefore, it is urgent to implement corrective measures that mitigate these negative impacts and restore water quality. By taking action, you can ensure the protection of aquatic ecosystems and ensure the sustainability of water resources for future generations.

***Keywords*— Water Quality, Water Sampling, Physico-Chemical Parameters, Microbiological Parameters, Statistical Analysis.**

I. Introduction

Water is vital to life, but in Honduras access to clean water is limited, especially affecting vulnerable populations that rely on untreated river water, increasing the risk of disease and scarcity.

The lack of water in Honduras is a worrying situation, since the amount available does not meet consumption needs, impacting both the domestic and industrial spheres, revealing that more than 50% of the national territory does not have a sufficient water supply. [1]

The environmental problem related to water is critical, especially in Tegucigalpa, the country's capital. Increasing urbanization, deforestation and lack of adequate infrastructure have exacerbated the water crisis. In addition, the discharge of raw sewage, industrial wastes and the expansion of informal settlements contribute to the deterioration of water quality. In addition, climate change and population growth could aggravate the demand for water in the country, making it necessary to optimize river management.

This combination of factors endangers both aquatic ecosystems and public health, requiring urgent and coordinated intervention to protect the water resources of Tegucigalpa and the rest of the country.

In this context, this research analyzes the quality of the water specifically of the San José River in Tegucigalpa, evaluating various strategic areas, divided by 4 stations in which the path of the San José River will be analyzed, from where it enters through the southern area of the capital to its mouth.

It is worth mentioning that for this research, appropriate techniques and standards will be used to collect samples, which will be analyzed in the laboratory, under a methodology validated by triangulation of experts.

Likewise, this study is crucial given that the San José River is one of the main tributaries of the Choluteca River, which also means an important water supply for the capital. In the same way, climate change and population growth could aggravate the demand for water in the country, making it necessary to optimize the management of river water.

In Honduras, the analysis of the management and importance of water in rivers has become relevant due to the problems that the country faces in terms of water supply and management; That is why some examples of research on this topic are the following:

In Honduras, an investigation of the surface waters of the micro-basin of the La Soledad River, Valle de Ángeles, was carried out with the objective of evaluating the quality and risk of contamination in the micro-basin of this river. The micro-basin was divided into nine drainage units, establishing sampling stations in each. Two samplings were carried out, one in the dry season and the other in the rainy season, between May and June. Several parameters such as nitrates, phosphates, total and fecal coliforms, temperature, pH, turbidity, and suspended, dissolved and total solids were analyzed, adjusting them to a Water Quality Index (AQI). In addition, the presence of organochlorine pesticides was investigated in two of the stations. [2]

Another similar study was carried out in the Arizona River Basin, department of Atlántida, Honduras, where a study was carried out to evaluate the quality of the water supplied to the population, a methodology was carried out that included visits to the area to collect data on the delimitation and generate land use maps. using geographic information systems (GIS). Sampling points were then selected at three key locations: the water source, the storage tank, and three taps in the urban center of the Arizona municipality. These samplings were carried out over three days over three months. The parameters of the micro-watershed were analyzed using the NSF AQI index, complemented with a multivariate statistical analysis of principal components. Finally, the results

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were compared with the limits established in the Technical Standard for Drinking Water Quality of Honduras of 1995. [3]

Similarly, in the department of Yoro, Honduras, on the Tascapala River, another research was carried out on the effects of riparian forest and anthropic activities on the physical-chemical characteristics and populations of aquatic macroinvertebrates in the sub-basin, where a physical-chemical, geomorphological and biological analysis of the water network in the sub-basin of this river was carried out. in twelve sampling points distributed between wooded areas and areas with agricultural and residential activities. Aspects such as the preservation of riparian vegetation, channel quality, dissolved oxygen, total solids, conductivity, temperature, turbidity, nitrates, orthophosphates, pH and fecal coliforms, as well as the presence of macroinvertebrates, were investigated. The findings showed that human activities have a negative impact on several parameters, particularly on fecal coliforms, pH, and turbidity. In addition, macroinvertebrates were identified as effective indicators of water quality and valuable tools for assessing the impact of conservation practices on watersheds. [4]

The scientific article is organized into several sections, which cover the methodology used in the research. This section is broken down into subsections detailing the focus and scope of the study, the variables examined, as well as the instruments and techniques employed, and the population and sample investigated. In addition, the article includes the results obtained, along with the conclusions and recommendations. At the end, there are sections dedicated to the applicability of the results and perspectives for future research, in order to establish a basis for future studies related to the research conducted.

II. Methodology

A. Focus and Scope

The focus for this research was quantitative. This approach seeks to achieve the greatest possible objectivity throughout the process since it follows a structured pattern guided by design. This approach not only contributes to the development of knowledge, but also ensures consistency in data analysis and collection [5]. The quantitative approach was specifically considered for this research as the appropriate one when the purpose was to obtain objective, precise data that could be explained and predict phenomena generating reliable and rigorous knowledge.

This research was based on the experimental scope. Since the experimental design consists of a series of steps planned in advance to ensure that the data collected is adequate and allows for objective analysis, leading to valid conclusions about the problem posed [6]. It is important to note that this research was guided by means of fundamentals of experimental design, obtaining precise results from various samples, which entails an exhaustive experimental scope.

B. Research Variables

Since independent variables are defined as explanatory, that is, the components or conditions have the potential to have influences on the variables that are dependent [7]. However, to carry out this research, some variables were considered as independent, such as the source of pollution and meteorological conditions. Such as: Source of pollution: Industrial, domestic or agricultural sources that may be influencing the state of the water and generating pollution to the San José River. And weather conditions: Factors such as rain or temperature that may be altering the levels of the water state.

Dependent variables are defined as the variables that are sought to be explained and answered, it is the focus of the research, which is intended to be understood in relation to other factors and the effect of independent variables is evaluated [8]. Specifically, for this research, the dependent variables would be all the parameters provided by the ICA. ICA-NSF: The parameters provided showing the true result of the water analysis by means of its calculation.

C. Applied Techniques and Instruments

1) Instruments Applied

- Thermometer: Instrument used to measure temperature quantitatively.
- Winkler bottle: Used specifically for the collection of biochemical oxygen demand.
- pH meter: Measures the alkalinity or acidity of the water.
- Incubator: Used in order to keep samples at a specific temperature throughout the incubation period.
- Turbidity meter: Measures the turbidity of the water taking into account how light is scattered being influenced by suspension particles.
- Funnels: Container that has the characteristic of having a hole with a tube to transfer substances to others that have small mouths.
- Beaker: frequently used in the laboratory, mainly to prepare or heat substances, measure or transfer liquids to other bottles.

2) Applied Techniques

The following techniques were used for the development of this research:

- Standardized tests performed in specialized laboratories.
- ANOVA Analysis of Variance: A statistical technique used to identify if there are significant differences between the means of three or more groups or treatments.
- Tool for the respective calculation of the water quality index (AQI) MS Excel.
- Minitab: statistical software designed for all types of organizations, which facilitates the analysis of complex data and the resolution of problems in mainly production processes.

D. Materials

- Latex gloves: As a protective measure against possible discovered risks.

- Distilled water: Purified water that removes most contaminants and impurities.

- Sterilized bottles: For the complete elimination of all bacteria without significantly affecting the organoleptic properties.

- Phosphate reagents: Chemical compounds used to identify the presence of phosphates.

- Nitrate reagents: Chemical compounds used to identify the presence of nitrates.

- Petri dishes: They are used to facilitate the development of microorganisms for evaluation.

E. Population and Sample

1) Population

In the present research, the delimited population was defined as the same 4 stations with different points.

- Station 1: This station was chosen for its geographical proximity as it is considered an entry point to the capital from the southern area.

- Station 2: Station chosen by the São Paulo Poultry Industry. There are indications that a company belonging to the poultry sector could be dumping its waste in this section of the San José River, highlighting the relevance of wanting to analyze the water of this specific station.

- Station 3: Station selected since at this point of San José River, colonies were found that discharge their wastewater for precarious reasons of sewerage and sanitation systems.

- Station 4: Selected station since at this point the San José River flows into one of the largest rivers in the region, the Choluteca River.

2) Sampling

The sampling used for this research was non-probabilistic for convenience since it was a continuation in which the population was already defined to give agreement. Likewise, it could not be a probabilistic sample because it required adequate representation of certain subgroups for which accessibility restrictions existed. That is why, for these and other reasons, non-probabilistic methods allowed for more targeted selection, while probability sampling might not have guaranteed this representativeness. Therefore, it was decided to use the same population size, i.e. the same four stations and samples conveniently. [9]

3) Sample

The research will be based on the same 4 stations, from which 12 samples will be collected in each, adding up to a total of 48 samples.

Compiling, since the 4 stations will be the same as the previous study, the criteria were taken in line with the same geographical proximities. Aspects such as industrial areas were taken into consideration, as well as the passage over colonies with deficient systems of pipes and wastewater drains, as well as a section of the mouth to another effluent that adjoins the San José River, broken down in the following order:

- Station 1: With its geographical coordinate of 14° 01'27.7"N 87°12'31.2"W and chosen due to its geographical proximity, it is considered an access point to the capital from the south.

- Station 2: With its geographical coordinate of 14° 01'58.4"N 87°12'25.1"W and chosen due to indications that a company in the poultry sector may be discharging its waste in this section of the river.

- Station 3: With its geographical coordinate of 14° 02'52.2"N 87°12'25.0"W and chosen for its urbanization and deficient sewage systems.

- Station 4: With its geographical coordinate of 14° 03'51.8"N 87°12'06.1"W and chosen for its mouth to other of the largest bodies of water in the region.

A total of 32 samples of 2L will be taken, with 8 samples collected at each of the 4 stations. Four of these samples from each station will be sent to a private laboratory to perform the Biochemical Oxygen Demand test, while the other 4 samples from each station will be analyzed in one of UNITEC's chemistry laboratories.

III. Results and Analysis

A) Results of sampling and inspected piloting

Specific criteria and indications were followed for the collection of samples. These instructions were provided during an informative talk on water analysis organized by CESCCO (Center for the Study and Control of Contaminants), where experts in the field offered direction and advice. In addition, a previous pilot was carried out that included appropriate techniques for sampling. Prior to defining the final results of the sampling, the relevant results of the pilot will be proposed.

For naming purposes of the 4 stations analyzed, the following nomenclature will be used: E1 refers to station 1, E2 refers to station 2, E3 refers to station 3, E4 refers to station 4.

Likewise, to identify the 4 points of each station, letters corresponding to the following nomenclature were assigned: A corresponds to the first point, B the second point, C to the third point, D to the fourth point. In this way, the combination of the letter with the station allows the sampling points to be accurately identified. For example, E1A corresponds to the first point of station 1, E4C to the third point of station 4, facilitating the organization and analysis of the data collected.

1) Inspected Piloting

To carry out the sampling, a previous pilot was carried out with the aim of learning and guaranteeing the correct use of the instruments, and taking samples, thus ensuring the obtaining of data with the greatest possible veracity. This piloting was carried out under the supervision of an expert, which gave it an inspection and validation character. During this phase, specific instructions were given for the proper use of the pH-meter, since pH is a parameter that must be measured immediately to avoid any alteration, as it can change over time. These instructions were based on the correct handling of the instrument in the university's chemistry laboratories.

After this training, the pilot was carried out in the E1A, starting with the collection of samples. The results obtained during the pilot were crucial in identifying and correcting errors in the process.

2) Final sampling

The sampling process at the four stations was carried out following a standardized procedure to ensure the consistency and quality of the data collected. We began with the preparation of all the necessary equipment and reagents. Instruments, such as the pH-meter and turbidimeter, were calibrated and proper sampling conditions were ensured, including cleaning the bottles and controlling water temperature and pH.

TABLE 1
STATION SAMPLING RESULTS

Station	Sampling Points	Sample Extraction Process	Techniques and Procedures Applied
E1	E1A, E1B, E1C, E1D	Collection of samples at different depths, labeling and preservation according to protocols..	Instrument calibration, bottle cleaning, standardized sampling techniques.
E2	E2A, E2B, E2C, E2D	Sampling at designated points, with care in handling and labeling.	Standardized procedures, temperature and pH control, rigorous cleaning.
E3	E3A, E3B, E3C, E3D	Sample extraction following the protocol to avoid contamination.	Use of calibrated equipment, preservation and labeling of samples, uniform techniques.
E4	E4A, E4B, E4C, E4D	Sample collection with attention to environmental conditions and sampling techniques.	Standardized techniques, cleanliness between samplings, transport under controlled conditions.

Source: Own elaboration

At each station, rigorous cleaning procedures were applied between each sample collection to prevent cross-contamination. The samples were transported in coolers to the different laboratories under controlled conditions for analysis at the ideal temperature, ensuring the validity and accuracy of the results obtained.

B) Results of Physical-Chemical and Microbiological Properties and Analysis using Statistical Tools

In this research, a total of 9 key parameters were analyzed to evaluate water quality defined by the AQI (Water Quality Index), which were: Dissolved Oxygen, Fecal Coliforms, pH, Temperature, Biochemical Oxygen Demand, Total Phosphates, Total Nitrates, Turbidity and Total Solids. Two of these parameters were analyzed in the chemistry laboratory of the university and were: Turbidity and Total solids. The Fecal Coliform parameter was performed by the researcher in the laboratories of a treatment plant in the accompaniment of an expert in the area.

However, two of these parameters, pH and temperature, were measured directly at the time of sample collection to obtain immediate data and avoid possible alterations. The remaining four parameters were analysed in an external private laboratory, due to the lack of reagents and specialised equipment in the university laboratory. This strategy ensured a complete and accurate assessment of all the physical-chemical and microbiological properties of the water, ensuring that the results are representative and reliable.

1) Parameters Analyzed by the Researcher: Results Obtained from pH

pH is a measurement used to determine whether a solution is acidic or basic, based on the concentration of hydrogen ions [H+]. In the case of water, pH is an essential chemical parameter that indicates its acidity or alkalinity. This value affects the availability of nutrients, the toxicity of certain metals and the activity of microorganisms in aquatic ecosystems. [10]

TABLE 2
PH RESULTS

PARAMETER	SAMPLE NUMBER	E1	E2	E3	E4
pH	A	6.7	6.49	6.16	5.7
	B	6.55	6.36	6.25	6.11
	C	6.54	6.25	6.2	6.16
	D	6.36	6.24	6.23	6.26

Parameters Analyzed by the Researcher: Temperature Results Obtained

TABLE 3
TEMPERATURE RESULTS

PARAMETER	SAMPLE NUMBER	E1	E2	E3	E4
T °C	A	23.1	23.3	23.4	23.4
	B	23	23.2	23.3	23.5
	C	23	23.2	23.3	23.7
	D	23.2	23.4	23.1	23.5

Source: Own elaboration

Temperature is a key physical variable that significantly impacts processes within the water. It affects the solubility of gases, such as oxygen, and salts, as well as being vital for biological reactions, which require a specific range of temperature to function efficiently. If the temperature is not right, these processes can suffer significant alterations. [11]

2) Parameters Analyzed by the Researcher: Turbidity Results Obtained

TABLE 4
TURBIDITY RESULTS

PARAMETER	SAMPLE NUMBER	E1	E2	E3	E4
Turbidity (unt)	A	85.3	90.2	88.1	92.5
	B	90.7	95.6	93.4	97.8
	C	92.5	96.1	93.7	103.3
	D	100.1	105.8	104.2	110

Source: Own elaboration

Turbidity is an optical characteristic of water, not a chemical or biological parameter. Therefore, when using it as an indicator of quality, it is important to do so with caution. High levels of turbidity do not necessarily imply that the water is in poor condition, and low levels do not guarantee its purity. For this reason, it is critical to analyze turbidity in combination with other factors to get a more accurate assessment of water quality. [12]

3) Parameters Analyzed by the Investigator: Total Solids Results

TABLE 5
TOTAL SOLIDS RESULTS OBTAINED

PARAMETER	SAMPLE NUMBER	E1	E2	E3	E4
Total Solids (mg/L)	A	0	0.1	0.3	0.8
	B	0	0	0.3	1.5
	C	0	0.1	0.40	1
	D	0	0.1	0.7	1.9

Source: Own elaboration

The term "solids" refers to any matter present in suspension or dissolved in a body of water. The measurement of total dissolved solids focuses on calculating the total amount of filterable waste, such as salts and organic compounds, through a membrane with pores of 2.0 µm or smaller. These solids are essential indicators for evaluating treatment processes and water quality. This parameter, which quantifies the concentration of suspended solids, is generally expressed in milligrams per liter (mg/l). [13]

4) Parameters Analyzed by the Investigator: Results Obtained from Fecal Coliforms

TABLE 6
FECAL COLIFORM RESULTS

PARAMETER	SAMPLE NUMBER	E1	E2	E3	E4
Fecal coliforms (UFC/100mL)	A	300	1800	3300	4300
	B	400	2900	3600	1900
	C	300	1600	1900	2100
	D	500	1600	3500	6500

Source: Own elaboration

Fecal coliforms are common contaminants that come from the gut systems of humans and warm-blooded animals. They are found in large quantities in the digestive tract and, in water, tend to be more resistant than pathogenic bacteria. Their behavior during disinfection processes is comparable to that of pathogens. It is concerning that these pathogens are also found in other rivers of Tegucigalpa such in the Valle de Angeles area [2]. Similarly in Latin America, specifically in Perú some studies have documented the presence of coliforms in water bodies such is the case of the study conducted in the Pantanos de Villa which highlights the significant presence of coliforms [19]. "To remove fecal coliforms, it is important to consider environmental factors such as humidity, temperature, UV light exposure, and pH. These microorganisms are more susceptible to being inactivated when they are in adverse conditions and lack essential nutrients for their development. [14]

5) Outsourced Parameters: Dissolved Oxygen

TABLE 7
DISSOLVED OXYGEN RESULTS

PARAMETRE	SAMPLE NUMBER	E1	E2	E3	E4
Dissolved Oxygen (mg/L)	A	7.25	7.14	7.39	6.76
	B	8.5	7.19	7.4	7.84
	C	8.86	7.32	7.07	7.01
	D	8.61	7.52	7.28	6.52

Source: Own elaboration

It is the measure of the amount of oxygen present in the water, taking as a reference the 100% oxygen saturation in the air. The level of dissolved oxygen is critical for the survival of organisms and the development of various processes within aquatic ecosystems. Living organisms need oxygen for their metabolism, which they obtain through respiration. For this reason, the measurement of dissolved oxygen is an essential indicator in water quality studies. [15]

6) Outsourced Parameters: Obtained Results of Biochemical Oxygen Demand

TABLE 8
RESULTS OBTAINED FROM BIOCHEMICAL OXYGEN DEMAND

PARAMETER	SAMPLE NUMBER	E1	E2	E3	E4
Biochemical Oxygen Demand (mg/L)	A	4.3	5.4	6.79	16.54
	B	4.23	4.87	6.03	30.56
	C	3.82	5.22	6.2	30.27
	D	6.2	5.11	6.72	16.2

Source: Own elaboration

Biochemical Oxygen Demand is a crucial parameter, as it measures the amount of oxygen that microorganisms need to break down organic waste in the presence of oxygen. This indicator is used to determine the oxygen required in the oxidation of biodegradable organic matter in a water sample, due to the aerobic processes involved. In addition, it is one of the main indicators for assessing the level of contamination in wastewater and plays an important role in monitoring the quality of drinking water. [16]

7) Outsourced Parameters: Total Phosphate Results

TABLE 9
TOTAL PHOSPHATE RESULTS

PARÁMETRO	NÚMERO MUESTRA	E1	E2	E3	E4
Fosfatos mg/L	A	0.08	0.13	0.28	0.25
	B	0.07	0.10	0.31	0.27
	C	0.15	0.05	0.09	0.28
	D	0.09	0.25	0.07	0.35

Source: Own elaboration

In natural and residual bodies of water, phosphorus occurs mainly in the form of phosphates, which can be dissolved or associated with aquatic organisms, from various sources. Phosphates are essential nutrients that encourage the growth of algae and aquatic plants. However, their presence in excess can trigger eutrophication, a process that deteriorates water quality, decreases oxygen levels and harms aquatic ecosystems. Therefore, it is essential to understand and control phosphate levels to preserve the health and balance of water bodies. [17]

8) Outsourced Parameters: Results Obtained for Total Nitrates

TABLE 10
TOTAL NITRATE RESULTS

PARAMETER	SAMPLE NUMBER	E1	E2	E3	E4
Nitrates mg/L	A	0.38	0.57	0.79	0.32
	B	0.33	0.51	0.76	0.25
	C	0.36	0.60	0.90	0.22
	D	0.34	0.62	0.86	0.19

Source: Own elaboration

Nitrates come mainly from the use of nitrogen fertilizers, animal excreta, discharges of sanitary and industrial waste, and food additives such as meat and fish preservatives. Likewise, its presence is closely related to the use of fertilizers in agriculture and pesticide residues. In surface water bodies, such as rivers and lakes, nitrate concentrations are usually low, usually in the range of a few mg/l, unless there is a significant source of contamination. In deep aquifers, nitrate levels are usually low, although they tend to be higher than in surface waters. [18]

9) Parameters Analyzed Using Statistical Tools

For this study, a basic statistical analysis was applied using the t-test of a sample for the parameters included in the Water Quality Index and in the tables of the Proposed National Technical Standard for Water Uses (PNTNUA), which are relevant for the preservation of flora and fauna and are determinant in the evaluation of basic water quality. A confidence level of 95% was set using the Minitab statistical program.

In order to compare the indices with stations, the following hypotheses were proposed:

- Null hypothesis (Ho): The values of laboratory results comply with the parameter established by the standard.
- Alternative hypothesis (Ha): The laboratory result values do not meet the parameter established by the standard.

TABLE 11
PARAMETERS ANALYZED BY THE T-TEST OF A SAMPLE

Parameters Ana zed byt-test of a sample								
Station	E1		E2		E3		E4	
Parameter	Ho	Ha	Ho	Ha	Ho	Ha	Ho	Ha
pH	✓		✓		✓		✓	
OD		✓		✓		✓		✓
DBO	✓		✓		✓			✓
Nitrates	✓		✓		✓		✓	
Fecal coliforms	✓		✓		✓		✓	

Source: Own elaboration

Table 11 shows that the parameter that does not comply with the PNTNUA standard is the OD exceeding the maximum permissible value. While the BOD parameter mostly complies, with the exception of E4, where the maximum permissible value is exceeded.

For this study, an analysis of variance was carried out using a single-factor ANOVA to evaluate each parameter measured at the stations. In addition, Tukey's method was used to identify in which stations there were notable variations in the results of each parameter. A 95% confidence level was used and the following hypotheses were established:

- Null hypothesis (Ho): There are no differences between the means of the stations.
- Alternative hypothesis (Ha): There are differences between the means of the stations.

Using the statistical software Minitab, in the statistics section, selecting ANOVA and the "Single-factor" option, a critical value of 3.49 was also used, which is obtained from the distribution table F for 0.05 with 3 degrees of freedom in the numerator and 12 degrees of freedom in the denominator. Analyses of variance were performed and Tukey's method was applied to verify the hypotheses raised.

However, the analysis of variance concluded that there is a significant difference between the parameters established by the ICA-NSF between the stations, as shown in the following table 12:

TABLE 12
PARAMETERS ANALYZED BY INTER-STATION ANALYSIS OF VARIANCE

Parameters Analyzed by Analysis of Variance		
Parameter	Ho	Ha
pH		✓
Temperature		✓
Turbidity	✓	
Total Solids		✓
Fecal coliforms		✓
OD		✓
DBO		✓
Total Phosphates		✓
Total Nitrates		✓

Source: Own elaboration

C) Calculation of the ICA-NSF

A calculator was used to obtain the Water Quality Index

(AQI) with the Excel tool developed by Rowan McCarthy, the averages and results of the laboratory tests were entered. This tool simplified the process by automatically calculating the Q- value, eliminating manual calculations and converting the results to a standard scale. In a matter of minutes, the value of the ICA-NSF is generated, streamlining the process and improving the accuracy of the analysis, reducing errors. In addition, it allows for easy interpretation of the results and ensures a high level of confidence in them.

TABLE 13
WATER QUALITY INDEX BY STATION

Station	Temp	DO	BOD	pH	TDS	Turb	NO3	Ecoli	PO4	Final WQI	Quality
	(°C)	(mg/L)	(mg/L)		(mg/L)	(ntu)	(mg/L)	(col/100mL)	(mg/L)		
E1	23.075	8.305	4.638	6.538	0	92.15	0.353	375	0.098	69.69	Medium
E2	23.275	7.293	5.15	6.335	0.075	96.925	0.575	1975	0.133	64.35	Medium
E3	23.275	7.285	6.435	6.21	0.425	94.85	0.828	3075	0.188	62.50	Medium
E4	23.525	7.033	23.3925	6.058	1.3	100.9	0.245	3700	1.288	48.55	Poor

Source: Own elaboration

The AQI-NSF calculation reflects the progressive degradation of water quality as you move through the seasons. It is important to note that the results of this calculation are influenced by the meteorological conditions in which the samples were taken, corresponding to a rainy season, during which the capital was under the influence of rainfall for several days.

Station E1 features a higher WQI, with a value of 66.40. In stations E2 and E3 a gradual degradation is observed, which reaches its lowest point in E4, with a WQI of 50.34. The first three stations are rated with "Medium Quality", while E4 shows "Poor Quality". The BOD parameter shows a significant increase compared to the other stations, especially in E4, where this value is significantly higher. In addition, E. coli levels are also higher in E4, indicating that this station is the most affected, as it receives the accumulated pollution from the previous stations, which is logical.

D)Research Validation

1) Triangulation by Experts

The current research received validation from four experts from various specialties, each with expertise in areas key to the study's success. Likewise, two experts reviewed the sampling in the field, while the analysis of the samples in the laboratory and the statistical analysis of the results were validated by UNITEC professors in Industrial and Systems Engineering. Below is a table specifying the advisors and areas in which the research validation was conducted.

TABLE 14 TRIANGULATION BY EXPERTS

Professional Titles of the Advisor	Experience	Validation Field
Chemical-Industrial Engineer	Teacher at UNITEC TGU	Chemical laboratory analysis
Bachelor of Biology	Laboratory Head of the Treatment Plant	Laboratory analysis and sample collection
Industrial Engineer	Teacher at UNITEC TGU	Statistical area
Bachelor of Microbiology	Head of the Environmental Microbiology Laboratory at CESCCO	Laboratory analysis and sample collection

Source: Own elaboration

The recommendations provided and adjustments made by the experts before, during and after the study helped to refine the methodology used and to ensure the accuracy and validity of the results. Expert triangulation strengthened the reliability of the project, providing a more solid and reliable foundation.

2) Piloting

The piloting allowed the researcher to become familiar with the sampling instruments and techniques, guaranteeing proper handling, such as the immediate use of the pH-meter, among other equipment, to avoid alterations. Expert supervision and real-time feedback added a layer of validation, correcting errors and optimizing the process before final sample collection. This prior learning ensured that the laboratory tests were performed correctly, thus reinforcing the reliability and quality of the results in the main phase of the research.

- Piloting Sampling

For the collection of samples, detailed criteria and guidelines provided during an information session organized by CESCCO (Center for Studies and Control of Pollutants) were followed, where experts offered guidance and recommendations. A previous pilot was carried out that included the appropriate techniques for the collection process, ensuring that the samples were taken correctly.

- Piloting for laboratory tests

In order for the researcher to become familiar with the tests and laboratory equipment, a previous pilot was carried out. This practice allowed the researcher to better understand the procedures, the proper use of reagents, and the handling of equipment and techniques. The piloting in the university's chemistry laboratory improved the accuracy and reliability of the results by perfecting the use of instruments and techniques, facilitated training in the handling of equipment, corrected errors, optimized methods, and strengthened the documentation and communication of findings, ensuring the quality and consistency of the research.

IV. CONCLUSIONS

i. The process of taking water samples in the San José River in Tegucigalpa had been carried out at 4 stations, each identified by a designated nomenclature that had facilitated its organization. This process, which involved the collection of 48 samples in total, had been carried out through supervised piloting and standardized procedures, which had made it possible to perfect the techniques and ensure the accuracy of the data. Piloting had been carried out for both sampling and laboratory testing, ensuring that handling was appropriate from collection to laboratory analysis.

ii. It is important to note that pH levels at stations E1, E2, E3, and E4 remained within the permissible range of 4.5 to 9.5, according to the PNTNUA for Use in Preservation of Flora and Fauna. Although the pH at E4 was slightly lower, with a minimum of 5.7, all values are within the acceptable range. A proper pH is essential to preserve the health of aquatic organisms and maintain the balance of the ecosystem. Therefore, the results indicate that the pH of the water in all seasons is appropriate for the preservation of flora and fauna, subsequently, determining its chemical property by means of the statistical tool t-test of a sample.

Through the analysis of variance and Tukey's method, it had been observed that most of the parameters evaluated presented significant differences between the stations, with the exception of one parameter that had not rejected the null hypothesis. It had been concluded that approximately 88.89% of the analyzed parameters had shown significant differences between the stations, while only 11.11% (turbidity) had not shown significant differences. In addition, the remaining 8 parameters had highlighted the significant differences between the stations, suggesting possible changes in water quality.

iii. It is important to note that the results of the ICA-NSF calculation were influenced by the weather conditions of the rainy season during the collection of the samples. The data obtained through this calculation showed that 75% of the stations evaluated received a rating of "Medium Quality". The water quality index score decreased from 66.40 WQI at station E1 to 50.34 WQI at station E4, which evidenced a progressive deterioration in the San José River from its entrance to the capital to where it empties.

iv. The validation of the study, which had included 12 consultancies in a 4-week period on piloting and peer review in Design of Experiments and related disciplines, had ensured that the development and results were accurate and reliable. The suggestions provided by CESCCO and experts in related areas, together with the participation of statisticians, had ensured accurate and representative sampling and analysis, minimizing potential bias and errors. This had facilitated the adequate progress of the research and had ensured that, when validating the results, they met the rigor and reliability required for this type of study.

V. Applicability / Implementation

This study is set up as a ready-to-implement proposal, offering a solid basis for future initiatives in water quality monitoring and management. The techniques and instruments used in the analysis are replicable in the field of environmental monitoring. The methodology used can be adopted by governmental agencies and non-governmental entities to detect and manage water pollution, update analytical methods and improve current scientific practices, thus contributing to the preservation and conservation of water resources.

VI. Evolution of Current Work / Future Work

With the conclusion of the current study on the quality index of the San José River, the next phase of the project will focus on addressing the detected fecal contamination issues and expanding the scope of environmental monitoring. In this second stage, the exact origin of the contamination will be identified, differentiating between human and animal sources, and the effectiveness of current waste management and water treatment strategies will be evaluated. The Design of Experiments approach will be used to perform a broader analysis, increasing the number of stations and samples, as well as the number of researchers.
Design of Experiments, as a statistical and engineering methodological support, will provide a more detailed and complete perspective, allowing the precise identification of the main sources and points of contamination, whether human or animal. This will allow for larger-scale data collection and evaluation of treatment strategies to optimize water quality.
With this phase of development, based on current research, it will be possible to identify the most effective strategies and measure their impact on reducing pollution.

References

[1] Robles Zúniga, E. W. (s. f.). Reducción de Escasez de Agua en Juntas de Agua del Distrito Central con Programación Lineal. 9. https://doi.org/10.18687/LACCEI2024.1.1.409

[2] Cardona, A. J. (2003). *Calidad y riesgo de contaminación de las aguas superficiales en la microcuenca del Río La Soledad, Valle de Angeles, Honduras.* [CATIE Centro Agronómico Tropical de Investigación y Enseñanza]. https://repositorio.catie.ac.cr/bitstream/handle/11554/3733/Calidad_y_riesgo_de_contaminacion.pdf?sequence=1&isAllowed=y

[3] Beltrán Alemán, L. A., Montero Fernández, I., Saravia Maldonado, S. A., Morales Lópe, D. N., Portillo Villanueva, J. D., & Arriaga Pérez, N. E. (2019). *Caracterización de los indicadores de calidad del agua en la microcuenca del río Arizona, Atlántida (Honduras)*. https://doi.org/10.5539/jas.v11n6p394

[4] García, L. A., & Jiménez, F. (2003). *Efectos del bosque ribereño y de las actividades antrópicas en las características físico-químicas y en poblaciones de macroinvertebrados acuáticos en la subcuenca del río Tascalapa, Honduras. 12.*

[5] Sampieri, R. H., & Torres, C. P. M. (2023). *METODOLOGÍA DE LA INVESTIGACIÓN* (Segunda). McGraw-Hill Education.

[6] Cárdenas, L. E. R., & Cortés, L. R. (2000). *Exploración al diseño experimental*. 9.

[7] Daniel Cauas. (s. f.). Definición de las variables, enfoque y tipo de investigación. 11.

[8] Daniel Cauas. (s. f.). Definición de las variables, enfoque y tipo de investigación. 11.

[9] Sampieri, R. H., & Torres, C. P. M. (2023). *METODOLOGÍA DE LA INVESTIGACIÓN* (Segunda). McGraw-Hill Education.

[10] Pool Herless, T. R., & Valverde Gómez, L. (2019). DETERMINACIÓN DEL PH Y CONCENTRACIÓN DE METALES TOTALES DE LAS AGUAS DEL RÍO CHIMÍN, DISTRITO CACHACHI - 2018 Y 2019 [Universidad Privada del Norte]. https://repositorio.upn.edu.pe/bitstream/handle/11537/22012/Tirado%20R%c3%ados%20Pool%20Herless%20-%20Valverde%20G%c3%b3mez%20Lenin.pdf?sequence=4&isAllowed=y

[11] Zamora Rodríguez, J. (2009). Parámetros fisicoquímicos de dureza total en calcio y magnesio, pH, conductividad y temperatura del agua pota ble analizados en conjunto con las Asociaciones Administra doras del Acueducto, (ASADAS), de cada distrito de Grecia, cantón de Alajuela, noviembre del 2008. 1-10.

[12] EPA. (2021a). FACTSHEET ON WATER QUALITY PARAMETERS Turbidity. 1-3.

[13] Vera Bravo, K. E., & Zambrano Zambrano, M. M. (2019). EVALUACIÓN DEL POLVO DE MORINGA (M. oleífera) PARA REMOCIÓN DE SÓLIDOS SUSPENDIDOS TOTALES EN AGUA RESIDUAL DEL CAMAL MUNICIPAL DE CALCETA. 1-57.

[14] Fuccz-Gamboa, J., Gómez-Moreno, R., Cárdenas-Guzmán, M., & Campos-Pinilla, C. (s. f.). COMPORTAMIENTO DE COLIFORMES FECALES COMOINDICADORES BACTERIANOS DE CONTAMINACIÓN FECAL EN DIFERENTES MEZCLAS DE BIOSÓLIDO Y ESTÉRILES UTILIZADOS PARA LA

RESTAURACIÓN ECOLÓGICA DE LA CANTERA SORATAMA, BOGOTA. 10.

[15] Polo Cobo, H. E. (2019). "ANALISIS ESPACIO TEMPORAL DE LAS VARIACIONES DE TEMPERATURA Y OXIGENO DISUELTO DEL ACUIFERO DE LA CIUDAD DE SANTA MARTA EN LOS AÑOS 2017 Y 2018" [Universidad Cooperativa de Colombia]. https://repository.ucc.edu.co/server/api/core/bitstreams/2a6a1a97-6466- 42b8-9d9a-7eeba0f40c26/content

[16] Raffo Lecca, E., & Ruiz Lizama, E. (2014). Caracterización de las aguas residuales y la demanda bioquímica de oxígeno. 1-10.

[17] Uriburu Chávez, L. S. (2018). DETERMINACIÓN DEL ÍNDICE DE CALIDAD DEL AGUA DE CONSUMO HUMANO, DEL CENTRO POBLADO DE AGUA FRESCA, DISTRITO DE CHONTABAMBA – 2018. http://repositorio.undac.edu.pe/bitstream/undac/710/1/Tesis%20URIBUR U%20CHAVEZ pdfUriburu Chávez, L. S. (2018). DETERMINACIÓN DEL ÍNDICE DE CALIDAD DEL AGUA DE CONSUMO HUMANO, DEL CENTRO POBLADO DE AGUA FRESCA, DISTRITO DE CHONTABAMBA – 2018.

[18] http://repositorio.undac.edu.pe/bitstream/undac/710/1/Tesis%20URIBUR U%20CHAVEZ pdf

[19] Edith M. Enrique-Ayala, Celina R. Gavidia Adriano, Alvaro M. Garriazo Suni, & Daniela Changanaqui Alfaro. (2021). Evaluación de la calidad del agua en los canales de la Zona de Reglamentación Especial de Los Pantanos de Villa (Lima, Perú). Publicado por la Universidad Científica del Sur (Lima, Perú), 1-10.