EVALUATION OF THE ECOLOGICAL STATE USING THE WATER QUALITY INDEX AND FLUVIAL HABITAT INDEX OF THE URBAN BASINS OF PANAMA

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ABSTRACT
The evaluation of the ecological status of aquatic ecosystems through indices allows quantifying and assessing the environmental impacts caused by human activities, in order to create a baseline for future adjustments in policies regarding environmental management, both at the level of local governments as nationals, who can collaborate in a better management of water resources. This study was carried out in the urban basins of Panama City, a place with the highest population concentration in the country, specifically in the Matasnillo, Juan Díaz and Pacora Rivers, in order to assess the ecological status using the water quality index (WQI) and the river habitat index (FHI). With the data collected from the samples in the high, medium and low zones, a Kruskall–Wallis Test was applied to determine if there were significant differences between the sampling points and in the season's characteristics of the tropical climate, the humid and dry, plus a sampling in and transition between both seasons. The results show us that the rivers maintain better conditions in remote areas or with less human impact, indicating that the upper areas of the Matasnillo, Juan Díaz and Pacora Rivers have the best scores in the WQI and FHI, decreasing their score in the middle and lower zones. The low WQI and FHI scores indicate the environmental impact caused by alterations to habitats due to canalization or construction of civil structures that end up modifying the hydrology, reducing the heterogeneity of habitats and the type of substrate, in addition to inadequate waste management, solids and liquids from human settlements, commercial and industrial activities, as well as agricultural areas in the rural perimeter that as a whole exert pressure on these urban basins as they pass.
Keywords: ecological estate, water quality index (WQI), fluvial habitat index (FHI), spatio-temporal analysis, Matasnillo River, Juan Diaz River, Pacora River, Panama.

1 INTRODUCTION

The health and quality of the waters in rivers and streams are of great importance for both human well-being and nature, for which the implementation of multimeric models for ecosystem studies using biological and chemical variables have been used frequently, obtaining results favorable for the management and identification of the conditions in the courses of superficial waters [1]. There is no doubt that one of the great challenges of this century is to seek to maintain the natural biological structure and functional attributes of aquatic ecosystems [2], case that is increasingly difficult, considering the destruction of natural habitats attenuated by the presence of pollutants in rivers that cross agricultural, industrial and urban areas [3].

On the other hand, hydrological variation can play an important role in the structure and relationships of river organisms between hydrology and biology that are influenced by flow

WIT Transactions on Ecology and the Environment, Vol 259,
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/AWP220081

regimes [4]. Being that according to Magoulick et al. [5], the hydrology–biology relationships must be examined within the flow regime. Furthermore, the variation of biological and hydrological characteristics at multiple spatial scales are important to conserve the natural flows of ecological relationships [6].

2 MATERIALS AND METHODS

2.1 Study area

2.1.1 Basin 142: Matasnillo River

The basin delimited between the Caimito and Juan Diaz Rivers, its extension is 383 km^2, the average elevation is 67 m above sea level and the highest point is 507 m above sea level, it is located in the Pacific of the Province of Panama. South main river is the Matasnillo that its total length is 6 km. It registers an average annual rainfall of 2,122 mm, it has a temperate tropical savannah climate, and its vegetation is made up of mature, secondary and little intervened forest); as well as grasslands and wetlands. This basin has other rivers of great importance such as the Curundu, Rio Abajo, Matias Hernandez and Cárdenas [7].

2.1.2 Basin 144: Juan Diaz River

The basin has an area of 322 km^2, located on the Pacific slope in the province of Panama. Its main river is the Juan Diaz, whose length is 22.5 km, with an average flow of 5.7 m^3 and average annual rainfall of 2,466 mm. The average elevation of 90 m above sea level and the highest point (800 m above sea level) is located between Cerro Azul and Cerro Jefe, it has a temperate tropical savannah and humid tropical climate. Among its tributaries are Las Lajas, María Prieta, Naranjal, Palomo, Quebrada Espavé and Malagueto [7].

2.1.3 Basin 146: Pacora River

It is located on the Pacific slope, within the province of Panama, in the district of Panama passing through the districts of Pacora and San Martín, between coordinates 8°00' and 8°20' north latitude and 79°15' and 79°30' west longitude. It maintains an area of 388 km^2. Among its natural limits we can mention: To the north, with the Chagres River basin; to the south, with the Bay of Panama; to the east, with the Bayano River basin; and to the west, with the Juan Díaz River basin. It is a basin considered a priority for the country, considering that it is the only source of surface water that supplies the Pacora water treatment plant. Its main course is the Pacora River, with a total length of 48 km, which rises in the mountains of the Cordillera Central to the Pacific Ocean, meeting its tributaries on its way, such as the Tataré River, Utivé River, Calobré River and Indio River, covering an area of 364 km^2. The highest point is Cerro Jefe (1,007 m above sea level). In the course of the basin there are three life zones: very humid premontane forest, humid premontane forest and tropical humid forest without the presence of protected areas [7].

2.2 Data analysis

2.2.1 Water quality index (WQI)

2.2.1.1 Spatial analysis of WQI

The data were collected in the wet season: September 2020, dry: March and transition: April 2021, in the high, middle and low areas of the basins 142: Matasnillo River, 144: Juan Diaz River and 146: Pacora River.

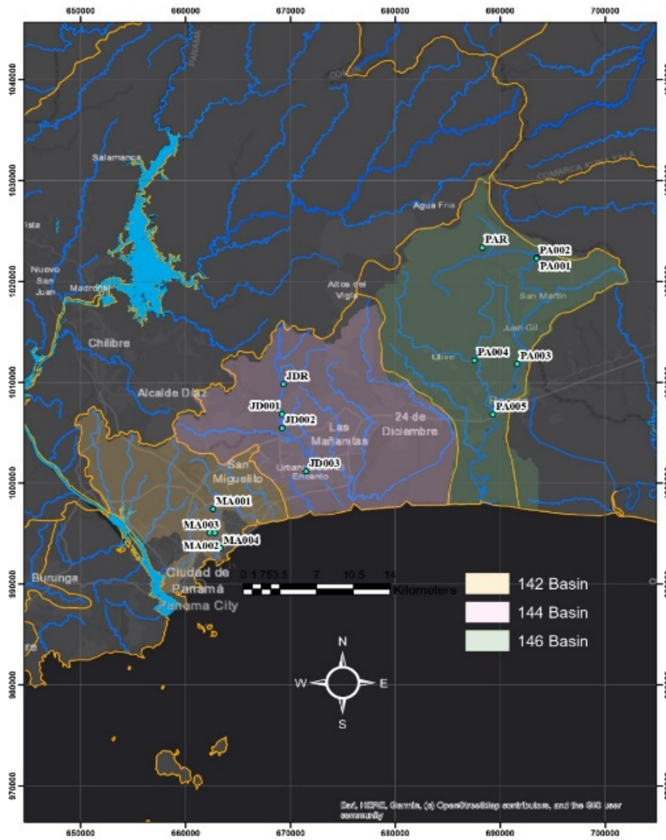


Figure 1: Location of the study sites.

The parameters used for the calculation of the WQI were T (°C), pH, DO (mg/L), fecal coliforms (NPM/100 mL), BOD_5 (mg/L), NO_3 (mg/L), and turbidity (NTU), using the standard methods as a guide [8]. Once the calculation is done, it will be categorized as highly polluted, polluted, slightly polluted, acceptable, and uncontaminated water quality.

The Kruskal–Wallis Test was applied to determine if there are significant differences for the WQI between points MA001, MA002 and MA003 Matasnillo River, JD001, JD002 and JD003 for Juan Diaz River and PA001, PA002, PA003, PA004, PA005 for Pacora River, using the statistical package PAST 4.01 and SPSS Version 28.

2.2.1.2 Temporal analysis of WQI

The Kruskal–Wallis Test was applied to determine if there are significant differences between the dry, wet and transition season of the WQI, using the statistical package PAST 4.01 and SPSS Version 28.

2.2.2 Fluvial habitat index (FHI)

The data were collected in the wet season: September 2020, dry: March and transition: April 2021, in the high, middle and low areas of the basins 142: Matasnillo River, 144: Rio Juan Diaz and 146: Pacora River.

For the FHI curriculum, an adaptation was made to the methodology used by Pardo et al. [10], categorizing from 0–100, very good, good and does not reach very good.

2.2.2.1 Spatial analysis of FHI

The Kruskal–Wallis Test was applied to determine if there are significant differences for the FHI between points MA001, MA002 and MA003 in the Matasnillo River, JD0001, JD002 and JD003 in the Juan Diaz River, PA001,PA002, PA003, PA004, PA005 in the Pacora River, using the statistical package PAST 4.01 and SPSS Version 28.

2.2.2.2 Temporal analysis of FHI

The Kruskal–Wallis Test was applied to determine if there are significant differences between the dry, wet and transition season of FHI, using the statistical package PAST 4.01 and SPSS Version 28.

3 RESULTS AND DISCUSSION

3.1 Basin 142: Matasnillo River

3.1.1 Water quality index (WQI)

The WQI values are presented in Table 1, which shows that for the points MA001WE, MA001DR and MA001TR they present values of 60 to 69 corresponding to the slightly polluted ratings. For points M002WE, MA002DR, MA002TR, MA003WE, MA003DR, MA003TR, MA004WE, MA004DR, MA004TR they present values of 35 to 47 corresponding to the polluted ratings.

3.1.1.1 Spatio-temporal analysis of the WQI

3.1.1.1.1 Spatial analysis

There are significant differences between points MA001, MA002, MA003 and MA004 according to the Kruskal–Wallis Test as shown in Fig. 2. The minimum WQI values were presented at point MA004 and the maximum values at point MA001 as described in Table 2.

3.1.1.1.2 Temporal analysis of the WQI

The temporal variations are in Table 2, according to the Kruskal–Wallis Test there are no significant differences between the dry, wet and transitional seasons.

3.1.2 Fluvial habitat index (HFI)

The FHI values are presented in Table 1, which shows that for the points MA001WE, MA001DR and MA001TR they present values of 50 to 58 corresponding to the good ratings. For points M002WE, MA002DR, MA002TR, MA003WE, MA003DR, MA003TR, MA004WE, MA004DR, MA004TR they present values of 25 to 48 corresponding to the ratings of not reaching good.

Table 1: WQI and FHI ratings of the monitored sites.

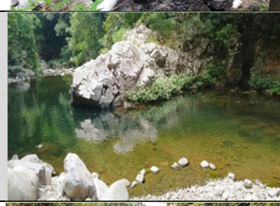
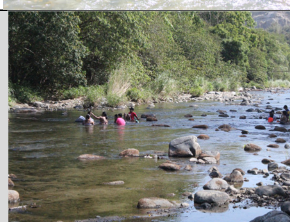
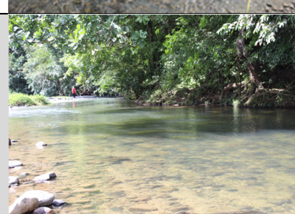
COD	WQI	FHI	Site
MA001WE	60	58	
MA001DR	62	50	
MA001TR	69	58	
MA002WE	35	48	
MA002DR	38	48	
MA002TR	39	48	
MA003WE	41	33	
MA003DR	45	33	
MA003TR	42	33	
MA004WE	36	25	
MA004DR	47	33	
MA004TR	44	25	
JDR	93	98	
JD001WE	83	88	
JD001DR	89	86	
JD001TR	93	88	
JD002WE	72	65	
JD002DR	82	65	
JD002TR	79	60	

Table 1: Continued.

COD	WQI	FHI	Site
JD003WE	46	45	
JD003DR	70	45	
JD003TR	58	40	
PAR	91	86	
PA001WE	76	72	
PA001DR	83	72	
PA001TR	92	72	
PA002WE	74	58	
PA002DR	75	58	
PA002TR	75	58	
PA003WE	73	54	
PA003DR	77	54	
PA003TR	73	67	
PA004WE	73	61	
PA004DR	79	61	
PA004TR	77	54	
PA005WE	68	50	
PA005DR	78	50	
PA005TR	76	57	

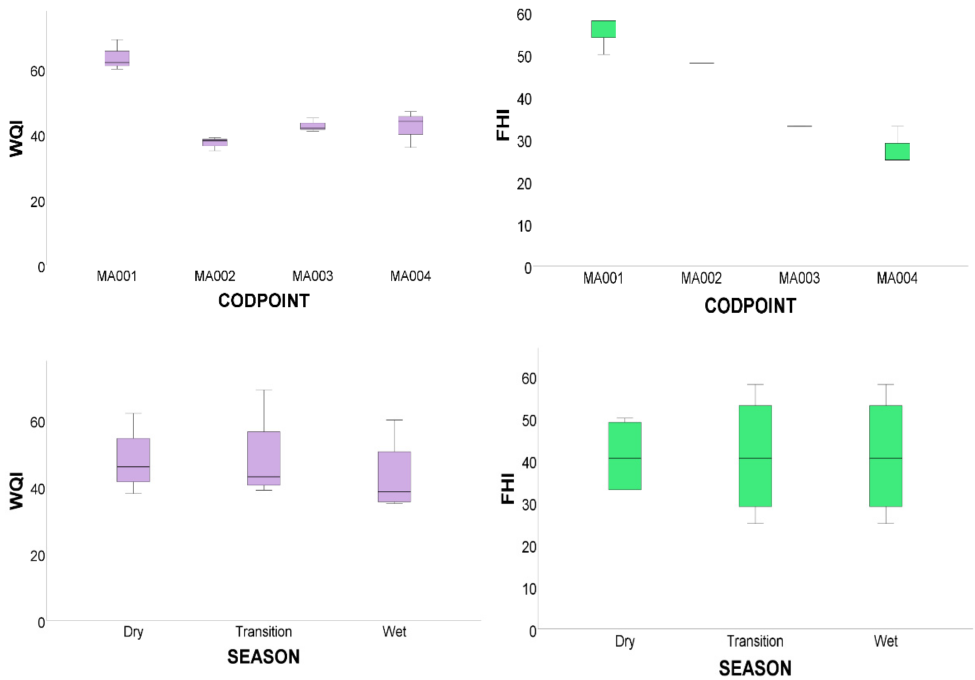


Figure 2: Boxplot of spatial-temporal variations of WQI and the FHI Matasnillo River.

Table 2: Descriptive statistics and Kruskal–Wallis of WQI and the FHI of Matasnillo River.

Index	N	Min.	Max.	Mean	Std. error	Variance	Std. dev.	Median	SEASON p (same)	CODPOINT p (same)
WQI	12	35	69	46.5	3.208653	123.5455	11.1151	43	0.4649	0.04344

3.1.2.1 Spatio-temporal analysis of FHI

3.1.2.1.1 Spatial analysis

There are significant differences between points MA001, MA002, MA003 and MA004 according to the Kruskal–Wallis Test as shown in Fig. 2.The minimum FHI values were presented at point MA004 and the maximum values at point MA001 as described in Table 2.

3.1.2.1.2 Temporal analysis

The temporal variations are presented in Fig. 2, according to the Kruskal–Wallis Test there are no significant differences between the dry, wet and transitional seasons.

According to the environmental monitoring carried out by ANAM [8], the Matasnillo River is classified as polluted to highly polluted, this due to domestic discharges and industrial activities, these waters being not suitable for use and aquatic life, except in the upper parts with restricted permission.

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3.2 Basin 144: Juan Diaz River

3.2.1 Water quality index (WQI)

The WQI values are presented in Table 1, the JDR point is a reference point, which exemplifies the ideal conditions, and we have not considered it for the present analyses. As seen in the table for points JD001WE, JD001DR, JD002WE, JD002DR, JD002TR, JD003DR present values from 70 to 89 corresponding to the ratings of acceptable, for point JD001TR with a value of 93, Uncontaminated, JD003TR presents the value of 58 slightly polluted, point JD003WE its value is 46 with contaminated rating.

3.2.1.1 Spatio-temporal analysis of the WQI

3.2.1.1.1 Spatial analysis

There are significant differences between points JD001, JD002, JD003 according to the Kruskal–Wallis Test as shown in Fig. 3.The minimum WQI values were presented at point JD003 and the maximum values at point JD001 as described in Table 3.

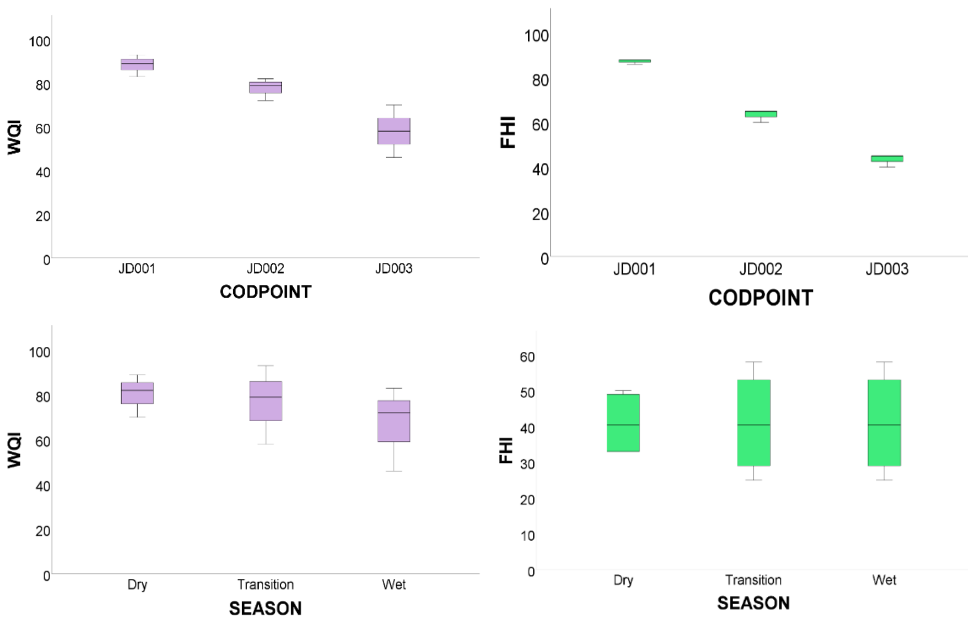

Figure 3: Boxplot of spatial-temporal variations of WQI and the FHI of Juan Diaz River.

Table 3: Descriptive statistics and Kruskal–Wallis of the WQI and FHI of Juan Diaz River.

Index	N	Min.	Max.	Mean	Std. error	Variance	Std. dev.	Median	SEASON p (same)	CODPOINT p (same)
WQI	9	46	93	74.66667	5.016639	226.5	15.04992	79	0.7326	0.02732
FHI	9	40	88	64.66667	6.398785	368.5	19.19635	65	0.9025	0.02491

3.2.1.1.2 Temporal analysis
The temporal variations are presented in Fig. 3, according to the Kruskal–Wallis Test there are no significant differences in WQI values between the dry, wet and transition seasons.

3.2.2 Fluvial habitat index (FHI)
The FHI values are presented in Table 1, which shows that for the points JD001WE, JD001DR and JD001TR they present values from 86 to 88 corresponding to the very good ratings. For points JD002WE, JD002DR, JD002TR have values of 60 to 65 corresponding to the ratings of good

JD003WE, JD003DR, MA003TR present values of 40 to 45 corresponding to the ratings of not reaching good.

3.2.2.1 Spatio-temporal analysis of FHI

3.2.2.1.1 Spatial analysis
There are significant differences between points JD001, JD002, JD003 according to the Kruskal–Wallis Test as shown in Fig. 3. The minimum FHI values were presented at point JD003 and the maximum values at point JD001 as described in Table 3.

3.2.2.1.2 Temporal analysis
The temporal variations are presented in Fig. 3, according to the Kruskal–Wallis Test there are no significant differences between the dry, wet and transitional seasons.

According to the analyses carried out by ANAM [8], they qualify as acceptable in the high areas, however the deterioration increases for the middle and lower areas of the river, presented ratings of contaminated or little contaminated, this due to the contributions of wastewater from population settlements, shops and industries.

3.3 Basin 146: Pacora River

3.3.1 Water quality index (WQI)
The WQI values are presented in Table 1, the PAR point with a rating of 93 is a reference, exemplifies the ideal conditions, and we have not considered it for the present analyses. As shown in Table 1 for the point PA001TR has a non-contaminated rating, points PA001WE, PA001DR, PA002WE, PA002DR, PA002TR, PA003WE, PA003DR, PA003TR, PA004WE, PA004DR, PA004TR, PA005DR, PA005TR have values of 73 to 83 corresponding to the ratings of acceptable, for point PA005WE with a value of 68 rating of contaminated.

3.3.1.1 Spatio-temporal analysis of WQI

3.3.1.1.1 Spatial analysis
There are no significant differences between points PA001, PA002, PA003, PA004, PA005 according to the Kruskal–Wallis Test as shown in Fig. 4.

The minimum WQI values were presented at point PA005 and the maximum values at point PA001 as described in Table 4.

3.3.1.1.2 Temporal analysis
The temporal variations are presented in Fig. 4, according to the Kruskal–Wallis Test there are significant differences in WQI values between the dry, wet and transition seasons.

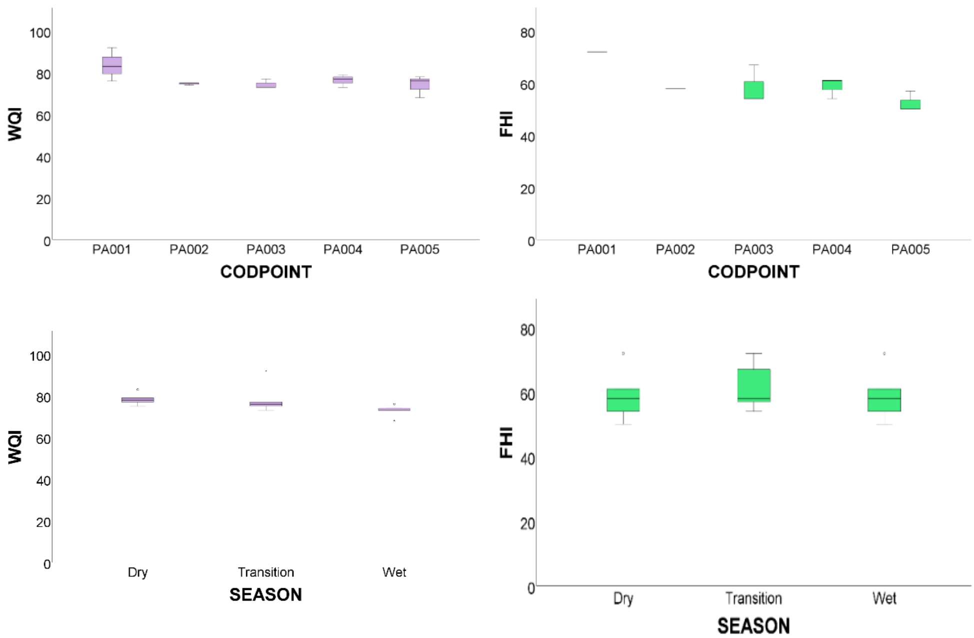

Figure 4: Boxplot of spatial-temporal variations of WQI and the FHI of Pacora River.

Table 4: Descriptive statistics and Kruskal–Wallis of WQI and the FHI of Pacora River.

Index	N	Min.	Max.	Mean	Std. error	Variance	Std. dev.	Median	SEASON p (same)	CODPOINT p (same)
WQI	15	68	92	76.6	1.4	29.4	5.422177	76	0.0375	0.3037
FHI	15	50	72	59.86667	1.966061	57.98095	7.614522	58	0.8842	0.04627

3.3.2 Fluvial habitat index

The FHI values are presented in Table 1, which shows that for the points PA001WE, PA001DR and PA001TR they present values from 72 to 86 corresponding to the very good ratings. For points PA 002WE, PA 002DR, PA 002TR, PA 003WE, PA003DR, PA 003TR, PA004WE, PA004DR, PA004TR, PA005WE, PA005DR, PA005TR they present values of 50 to 67 corresponding to the good ratings.

3.3.2.1 Spatio-temporal analysis of FHI

3.3.2.1.1 Spatial analysis

If there are significant differences between points PA001, PA002, PA003, PA004, PA005 according to the Kruskal–Wallis Test as shown in Fig. 4. The minimum FHI values were presented at point PA005 and the maximum values at point PA001 as described in Table 4.

3.3.2.1.2 Temporal analysis

The temporal variations are presented in Fig. 4, according to the Kruskal–Wallis Test there are no significant differences between the dry, wet and transitional seasons in the FHI.

According to ANAM [8], the Pacora River has an acceptable rating, this allows the development and consumption for agricultural, recreational and commercial activities, as well as the presence of aquatic life.

4 CONCLUSION

The results obtained in this study indicate that high areas of the Matasnillo, Juan Diaz and Pacora Rivers have the best ratings in the WQI and in FHI, decreasing their score in the middle and low areas.

In the application of the Kruskal–Wallis Test for the spatial analysis of the WQI in Matasnillo and Juan Diaz Rivers there are significant differences between the sampling sites, except in the Pacora River, for the case of the temporal analysis of the WQI for the Matasnillo and Juan Diaz Rivers there are no significant differences except in Pacora River.

The application of the Kruskal–Wallis Test for the spatial analysis of the FHI in the Matasnillo and Juan Diaz Rivers there are significant differences between the sampling sites except in Pacora River, for temporal analysis of the FHI in the Matasnillo, Juan Díaz and Pacora Rivers there are no significant differences between the wet, dry and transitional season.

Low WQI and FHI scores indicate the environmental impact caused by inadequate management of solid and liquid waste from human settlements, commercial and industrial activities that put pressure on these urban basins.

ACKNOWLEDGEMENTS

This research was financed by the Scholarship of the Subprogram of Doctoral and Postdoctoral Scholarships of the National Secretariat of Science and Technology (SENACYT) in conjunction with the Institute for the Training and Use of Human Resources (IFARHU). This research is part of the project Environmental Impact of Multiple Stressors in Aquatic Ecosystems of the Metropolitan Area of Panama, financed by SENACYT.

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