International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.10 No.15, pp 421-432, 2017

Multivariate analysis of surface water quality of the Bay of Cartagena (Colombia) period 2001-2017

Baldiris-NavarroI.*[1], Acosta-Jimenez J.C.[1], Martinez-Pajaro C.E. [1], Sanchez-Aponte J.[1], Castro-Angulo I.[1], Severiche-Sierra C.A.[1,2]

[1]University Foundation Technological Comfenalco, CIPTEC Research Group. Cartagena de indias-Colombia
[2]University of Cartagena, MAAS Research Group MAAS. Cartagena de indias-Colombia

Abstract : Cartagena Bay is directly affected by wastewater discharges from the city of Cartagena de Indias, its industrial zone and the mouth of the Magdalena River (Dique Canal). Multivariate statistical analyzes such as cluster analysis and principal components were used to evaluate the spatial variation of water quality at thirteen points of the bay during the period 2001- 2016. The results were compared with national water quality guidelines for secondary contact water. It showed that Dique Canal impacted in the concentration of solids in the whole bay and produced outliers out of the acceptable range for this parameter. Wastewater from residential areas, boats, Dique Canal and industrial area contaminate the bay with faecal coliforms which may become a public health problem due the high levels of this parameter (eg 19,000 NMP in residential areas). Salinity is below recommended values for the conservation of existing coral species in the bay. In addition, the phosphorus concentration is above the limit to avoid eutrophication of the water body. Three factors were identified as responsible for the data structure, explaining 88.1% of the total variance. The first factor is due to nutrients parameters explaining 56,5% of the total variance. The second and third factors are, respectively, the biochemical (19,91%) and anthropogenic (11,67%). The clustering procedure highlighted three different groups in which the sampling sites have similar characteristics and pollution levels. Cluster one and two have moderate pollution levels, but cluster three is a highly polluted one.
Keywords : Multivariate statistical techniques, Spatial variation, Temporal variation, Water quality.

Introduction

Coastal ecosystems have been altered globally as a consequence of industrial, commercial and population growth[1]. Coastal wáter quality is governed for both by manmade (spatial, anthropogenic) pollution and natural processes (temporal, climatic). Anthropogenic influences are viaurban, industrial, and agricultural activitieswhile natural processes are via precipitation input, erosion, and weathering of crustal materials[2,3].

Cartagena bay is an important trade port and tourist area of the Colombian Caribbean. In the bay exist an industrial economy with companies producing chemical substances, plastics, leather tanning, cement, metal mechanics, refineries, pesticides and food processors. In addition, the bay has 52 docks, 17 engaged in international trade. The industrial zone of Cartagena concentrates 70% of the petrochemical sector of the

Caribbean region of Colombia[4,5]. These companies, despite having waste water treatment plants, discharge a large quantity of pollutants into the Cartagena bay, which negatively impacts the quality of water.

In the middle of the seventeenth century the Bay of Cartagena began to receive discharges of fresh water loaded with sediments, due to the interconnection of a series of marshes and the dredging of pipes that gave rise to the Canal del Dique. The latter was built in order to facilitate communication between Cartagena and the interior of the country through the Magdalena River. At present, the Canal del Dique has an approximate extension of 106 km and transports near 10 million cubicmeters of sediments a year, of which 35% arrive in the Bay of Cartagena[6]. Near the mouth of the Canal are shrimp companies and agricultural farms that discharge their effluents into the Dique Canal and reach the bay.

The Canal and the industrial zone, alongwith other anthropic factors, have affected the hydrographic and sedimentological conditions of the bay until it is now a days the characteristics of anestuary, modifying the structure of biological communities[7]. A species of concern for their survival in the bay of Cartagena are coral reefs, which are a species that has been disappearing in the bay by the predatory action of man and pollutants thrown into the marine ecosystem[8].

The descriptive statistics (mean, SD, etc.) and some graphical aids may give a too simple assessment of wáter behavior. The problem of evaluating wáter quality becomes more and more complicated as we increase the number of measured variables; then the use of both multivariate techniques and data reduction are almost mandatory to achieve satisfactory results[9]. Multivariate analysis techniques such as cluster analysis (CA) and principal components analysis (PCA) may be used to analyze large databases without losing valuable information[10,11].

PCA and CA technics have been widely used to evaluate wáter quality, identify the latent sources that influence surface water, and offer a valuable tool for reliable management of wáter resources as well as effective solutions to pollution in the last decade. Taoufik et al.(2017)[12]studiedthevariation of wáter quality in ther iver Wadi El Bey during two years using PCA y cluster analysis. Hajigholizadeh et al. (2017)[13]used cluster analysis and discriminant analysis to study southern Florida wáter quality, analysing a 15-year database and over 35,000 observations to assess the state of wáter pollution and its time-space variation. Tosic et al.(2017)[14] used basic descriptive statistics to explain the temporal variation of wáter quality and sediments in the Bay of Cartagena.

Yoon et al.(2016)[15]studiedthe temporal and spatial variation in Chilikalagoon using PCA and data collected from 1999 to 2009. Jung et al.(2016)[16] analyzed the behavior of wáter quality in the Nakdong River basin by principal component analysis and cluster analysis. Through principal component analysis and cluster analysis Jiang et al.(2015)[17]studied the distribution of arsenic and other compounds in ground water in Mongolia. Marinovic et al.(2015)[11]by PCA and CA analyzes determined a baseline of wáter quality of the sava-croatia river after the war in this country. Pati et al. (2014)[18]evaluated the variation of WQI (wáter quality index) for a coastal zone in India by cluster analysis and discriminant analysis.

The aim of the present study is to analyze the variability of wáter quality during the period 2001-2017 in thirteen points of the Cartagena bay and also provide scientific references for the management of this bay water in the future.

Experimental

Study area

Cartagena bay is located on the Colombian Caribbean Region, north of the department of Bolivar, at coordinates 10 ° 26 'north latitude and 75 ° 33' west longitude. The Bay has an approximate extension of 72 km2 limiting with the islands of Tierra Bomba and Barú, and has an average depth of 21 meters[19]. The temperature in the city registered a mean value of 31.5 ºC, with its highest values in the months of June, July and August with averages between 31.9ºC and 32.0ºC, and its minimum values between January and March, with averages between 31.0ºC and 31.1ºC. In rainy season (April to November) rainfall ranges between 29 and 244 mm / month and in dry season (December to March) rainfall means vary between 1.0 and 37 mm / month[20].

Sampling stations

Local authority designed a monitoring plan which contains thirteen (13) sampling points. The distribution of the sampling stations is shown in 1. Stations 2, 3, 6 and 9 are located in the industrial zone and near the mouth of Dique Canal, where there are Refineries, petrochemical companies, food processors, ports, etc. Points 4, 10, 12 and 13 are located in residential areas, port and tourist areas. Points 1, 5, 7, 8 and 11 are areas close to small towns with low economic activity. Samples were taken twice a year at the thirteen points concerning to this study.

Figure 1. Map of theBay of Cartagena

The selection of monitored parameters was made following the recommendation of local authorities. Analytical methods were standard; APHA (2012)[21]method numbers and other methods are cited in parentheses. Measured parameters include: ammonia (4500-NH3 C, direct); 5-day biological oxygen demand (SM 4500-O G) dissolved oxygen (DO) (SM 4500-O G); nitrates (SM 4500-NO3- E) pH (SM 4500-H+ B, field measured); total solids (SM 2540-D); temperature (SM 2550-B, field measured); total coliforms (SM 9222 B); salinity (SM – 2520-B), total phosphorus (SM 4500-P B, E). All the analyses were run in duplicate. At each sampling point were measured in situ; pH, salinity and OD. Refrigerated samples were taken for TS, BDO5 and nitrate, ammonium and phosphorus assays. Samples preserved with EDTA for total coliform tests were also taken[21].

Data Analysis

In this study, data were not normally distributed due to a high number outliers. Therefore, median and MAD values for each parameter were used. The choice of using median rather than mean was based on the fact that the values were quite skewed. Non-parametric Kruskalwallis test was used to detect possible differences between the medians of water quality variables in stations[22]. Hierarchical agglomerative cluster analysis was performed by Ward's method, using squared Euclidean distances as a measure of similarity between sampling stations[23]. Principal components analysis was applied to obtain composite variables, which was expected to identify factors affecting water quality and latent pollution sources[24]. All mathematical and statistical computations were made using Excel 2013 (Microsoft Office) and R Version 3.3.1

Results and discussion

The statistical summary (median, mad, maximum and minimum) of the measured parameters in seawater samples from the 13 monitoring stations between 2002-2017 is provided in Table 1.

Table 1. Descriptive statistics of the parameters measured in Cartagena bay

		NH_4	DBO_5	P	NO_3	OD	pH	TEM	SST	SAL	CT
Tierrabomba	M	0,11	1,12	0,04	0,01	7,43	8,18	28,85	20,50	32,00	4,00
P1	MAD	0,04	0,65	0,01	0,00	0,33	0,05	0,95	14,20	4,15	30,00
	Min	0,07	0,31	0,03	0,01	3,75	7,04	26,30	4,00	0,10	1,80
	Max	0,95	2,88	0,48	0,04	9,92	8,70	31,10	150,00	46,00	1300
Alcalis	M	0,16	2,6	0,095	0,034	7,49	8,18	30,6	23,33	23	230
P2	MAD	0,09	1,05	0,055	0,024	0,72	0,14	1,35	10,67	7	207
	Min	0,07	0,46	0	0,000	4,4	7,87	28,5	0	0,1	1,8
	Max	0,576	7,31	0	0,000	11,31	8,82	38,5	0	35,6	24,000
Cotecmar	M	0,3	1,69	0,07	0,109	7,9	8,22	30,6	24	20	535
P3	MAD	0,23	0,84	0,028	0,097	1,075	0,11	0,7	13,2	9	535
	Min	0,07	0,31	0,04	0,012	4,9	6,03	27,5	8	0,012	7
	Max	0,87	4,52	0,19	0,574	11,4	8,63	33,1	122	41	490,000
Oceanario	M	0,18	0,34	0,06	0,022	7,21	8,175	29,65	16	32	12
P4	MAD	0,11	0,05	0,02	0,010	0,69	0,155	0,7	14	4	29
	Min	0,07	0,27	0,031	0,000	5,76	7,81	27,5	0	0,1	2
	Max	5,11	1,34	0,05	0,000	9	8,5	30,6	0	36,2	2400
Bocachica	M	0,155	1,18	0,05	0,036	8,18	8,225	29,5	19,5	21,5	220
P5	MAD	0,085	0,72	0,019	0,024	0,645	0,105	1,05	11,1	8,5	203,5
	Min	0,07	0,31	0,031	0,010	6,01	7,84	27,1	8	0,1	2
	Max	0,76	3,24	0,26	0,080	9,76	8,5	31,7	64	44	2100
Corelca	M	0,215	1,4	0,06	0,050	7,86	8,24	30,1	17,8	20,35	270
P6	MAD	0,145	0,84	0,02	0,038	0,675	0,13	1,1	10,2	9,65	270
	Min	0,07	0,31	0,03	0,010	4,7	6,64	27,5	7,6	0,1	2
	Max	1,06	4,2	0,32	0,417	10,68	8,77	32,7	146	37	4600
Caño Loro	M	0,29	1,2	0,05	0,083	7,67	8,21	30,2	17	16,03	210
P7	MAD	0,22	0,61	0,019	0,059	0,465	0,115	1,2	9,5	7,13	198,97
	Min	0,07	0,31	0,031	0,011	4,8	7,12	27,5	8	0	2
	Max	0,91	3,56	0,18	0,263	10,05	8,8	34,6	142	42	350,000
Polvorin	M	0,14	1,37	0,07	0,031	7,69	8,21	29,85	16,8	26,6	185
P8	MAD	0,07	0,9	0,03	0,019	0,7	0,13	0,95	8,8	7,5	158,4
	Min	0,07	0,31	0,031	0,010	4,6	7,25	27,5	9	0,1	1,8
	Max	0,91	3,52	0,13	0,191	9,4	8,56	32,3	206	39	1300
Canal del Dique	M	0,15	1,15	0,24	0,276	6,14	7,555	30	230	0,05	1650
P9	MAD	0,08	0,5	0,13	0,159	0,64	0,215	0,5	148	0,05	1649,95
	Min	0,07	0,31	0,06	0,012	1,15	6,42	28,5	13,5	0	11
	Max	0,97	4,07	0,67	0,733	7,75	8,39	32,4	728	35	790,000

Bocagrande	M	0,25	1,38	0,06	0,012	7,42	8,17	29,8	44,8	35,45	7
P10	MAD	0,18	0,77	0,03	0,002	0,55	0,125	1,05	26	1,45	28,45
	Min	0,07	0,31	0,03	0,012	5,65	7,76	27	36	0,1	1,8
	Max	0,65	3,08	0,1	0,014	8	8,5	32,5	247	40,7	490
Escollera	M	0,225	1,24	0,057	0,019	7,71	8,22	28,8	16,2	26,55	43
P11	MAD	0,225	1,24	0,057	0,019	1,305	0,515	1,9	16,2	16,5	26,55
	Min	0,07	0,31	0,031	0,010	5,4	6,97	26,9	10	0,1	1,8
	Max	1,09	4,27	0,21	0,121	11,26	8,93	31,6	181	43	2400
Boya verde	M	0,19	1,8	0,07	0,020	8,02	8,215	28,8	16	27,85	170
P12	MAD	0,18	1,325	0,07	0,017	1,305	0,185	1	13	10,05	170
	Min	0,07	0,31	0,031	0,010	3,9	6,83	27,5	0	0,1	1,8
	Max	1,07	5,6	0,36	0,386	10,42	9	31,4	145	44	17000
Acuacar P13	M	0,365	2,04	0,055	0,034	7,62	8,245	30,1	17,6	21,7	140
	MAD	0,211	0,84	0,021	0,022	0,58	0,125	1,15	10,5	8,3	128,3
	Min	0,07	0,54	0,03	0,01	4,3	5,16	27,8	7	0,1	1,8
	Max	0,78	7,72	0,16	0,338	10,7	8,65	32,2	153	42	240,000

Table 1 shows that mean DO values at the sampling points correspond to those permissible by Colombian law. However, there were decreases of this variable, reaching a minimum value of 1.15 mg / L at the mouth of DiqueCanal, probably due to industrial dumping in the area bordering the Canal, where shrimp industries are located, which might cause low values of DO in water due to the high levels of nutrients and organic matter.

Temperature directly affects many of the biological and physicochemical processes present in water bodies, including nutrients, oxygen, etc. Excessive increases in temperature may deoxygenate a body of water very quickly. High atypical values in water were found, as recorded in BoyaRojastation in front of Cotecmar with values of 38.5 ° C during the wet season.

The biochemical oxygen demand (BOD^5) is a measure of the amount of oxygen consumed in biochemical degradation of organic matter by aerobic biological processes. For BOD^5 data the statistic of the Kruskal-Wallis test was 37.12 with a p-value lower than 0.05, so there is a statistically significant difference between the medians of the stations with a level of 95, 0% confidence, although there are stations that have a similar behavior. All the sampling sites comply with the legal regulations for the median, represented by the dotted line, which stipulates a maximum value of 3 mg / L for this parameter. The box plot showed values of deviations above the normativity in Alcalis, Boya Verde and Acuacar as can be seen in 2. These points are located in residential, tourist and industrial zone which indicates a high contamination by domestic and industrial waste water in these zones. The aquacar station was a point of wastewater discharges from the old sewage system of the city that explains this behavior.

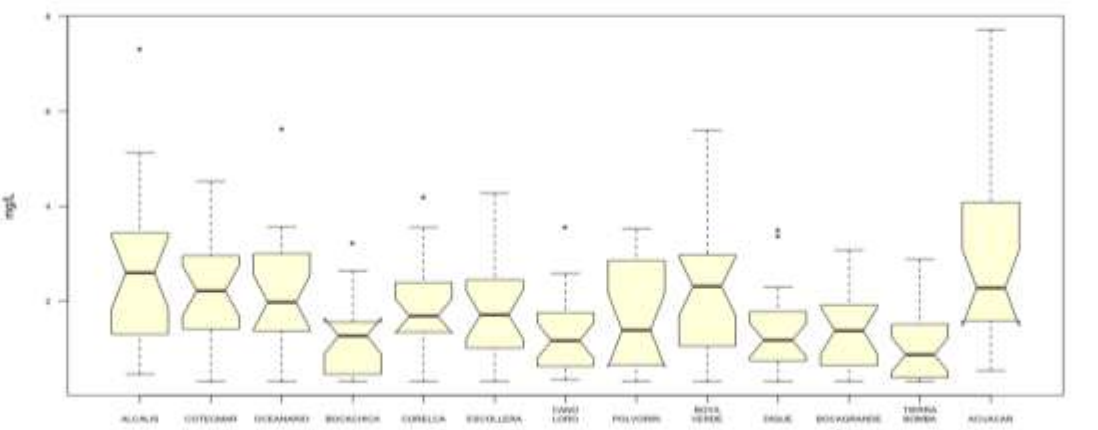

Figure 2. Box plot of BOD_5 in all stations

Constant discharges from the Dique Canal, discharges from inefficient wastewater treatment plants and runoff from rainwater coupled with other factors provide the bay with not only suspended particles but also pathogenic microorganisms which may cause severe infections to people and public health issues.

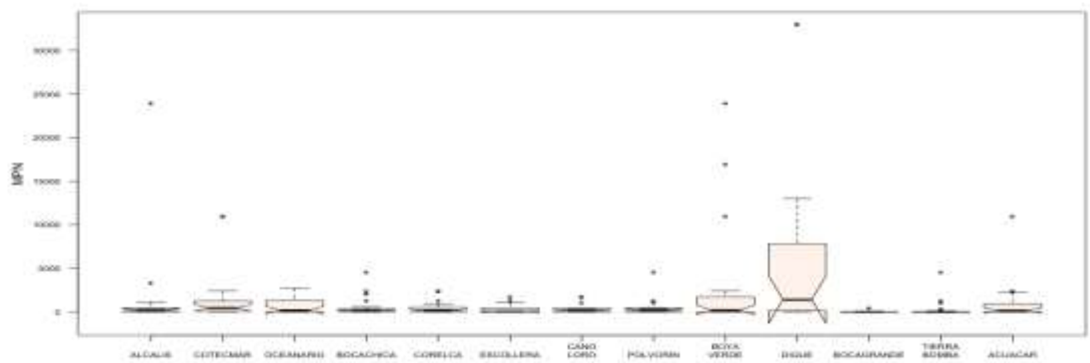

Figure 3. Box plot of total coliform in all stations

In Cartagena bay, Kruskal-Wallis test (Statistic = 56.1626, p-value = 1.118E-7) showed a statistically significant difference between the medians of the sampling stations with a level of 95.0% confidence. Total coliform values in the bay were found above the maximum set by the regulation (≤5000 NMP). At Cotecmar station the maximum registered value was 490,000 CT-NMP, in CañoLoro a maximum of 350,000 NMP was obtained, at the mouth of the Dique Canal was 790,000 NMP. Again, Boya Verde station, which is a residential and port area, is highly contaminated by total coliforms (max = 17,000 NMP) that can be caused by domestic and boats sewage.

For total solids data, Kruskal-Wallis test yielded a Statistic of 57.98 and a p-Value of 5.23E-8, this means that exist a statistically significant difference between the medians with a level of 95.0% confidence and this can be evidenced in boxes and whiskers plot, where the station Dique Canal has a different behavior to the rest of stations. Figure 4 shows that all stations present non-compliance in this variable, this is probably caused by the effect of the DiqueCanal on the entire bay.

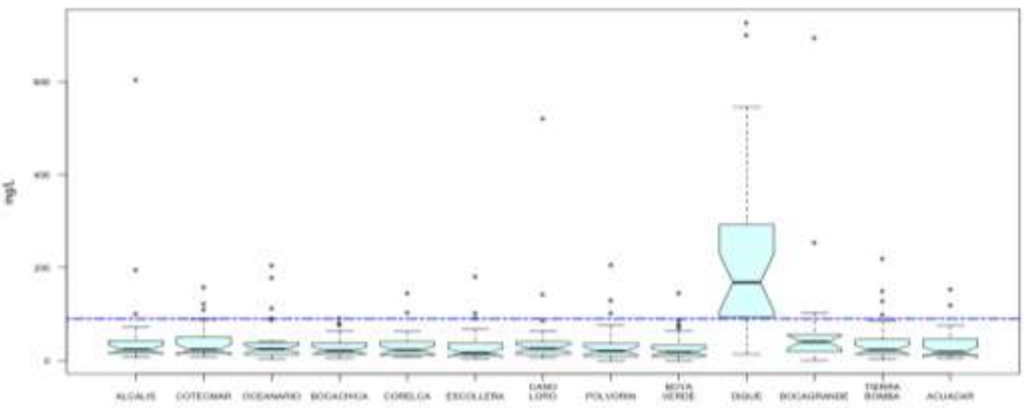

Figure 4. Box plot of total solids in all stations

Kruskal-Wallis test yielded a statistic of 31.73 and a p-value of 0.002. Since the p-value is less than 0.05, there is a statistically significant difference between the medians of the sampling points with a level of 95.0% confidence for phosphorus. In this analysis the median concentration of phosphorus exceeded the value recommended by different authors (<3 ug / L) for the thirteen study sites. This condition poses a risk to the coralline life existing in the Bay, because macroalgaes proliferate reduced coral cover. Phosphorus concentration reached eutrophication level in Cartagena bay due to many income ways of this nutrient (Dique Canal, industrial wastewater and residential sewage).

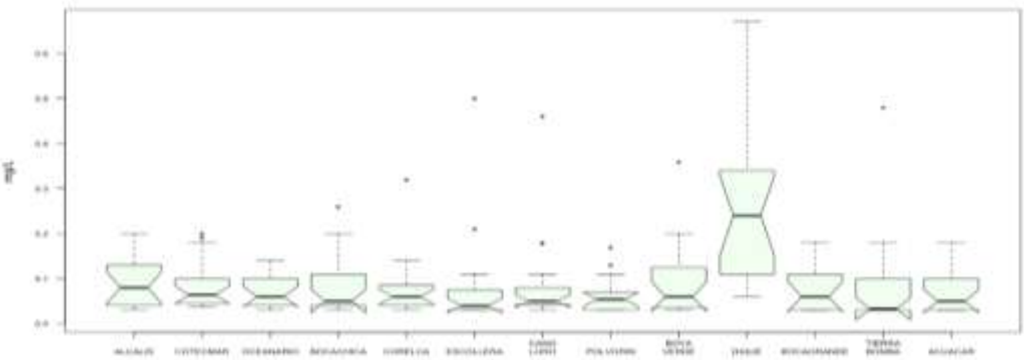

Figure 5. Box plot of phosphorus in all stations

Corals are characterized by a weak tolerance to variations in salinity, this variability causes an increase in the occurrence of diseases in coral reefs. The Kruskal-Wallis test established that there is a statistically significant difference between the medians with a 95.0% confidence level, which might be caused by freshwater entering via DiqueCanal and the dumps of industrial companies, which causes a drop of salinity in monitoring stations.

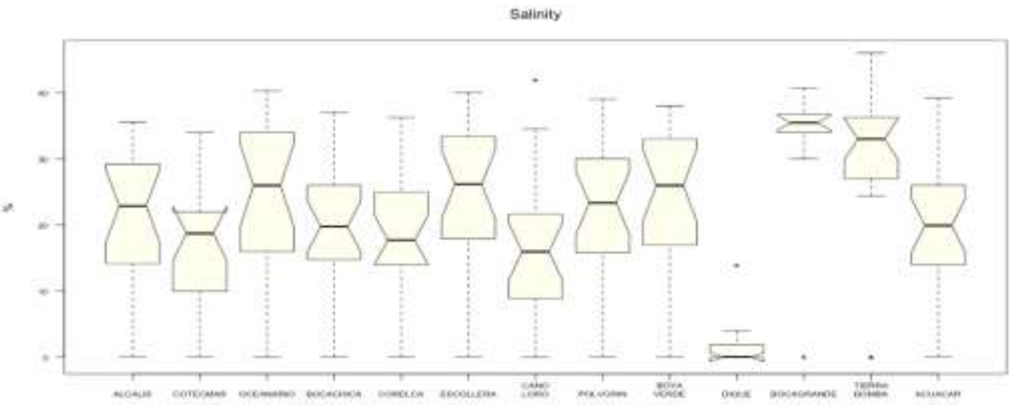

Figure 6. Box plot of Salinity in all stations

Box and whiskers plot showed that in Cartagena bay there is a high variability in this parameter, it reached minimum values of 0.1 and maximum of 46. The thirteen sampling points have characteristics that may cause diseases such as whitening in coral reef.

The range established by regulations for pH is 6.5 to 8.5. This variable was among the allowable levels for this parameter at all sampling points (see Table 1). The Ministry of Environment and Sustainable Development sets 1 mg / L as limit for ammonium. This parameter was kept below the maximum allowable in all the stations as shown in Table 1. The maximum accepted value for nitrates is 5 mg / L, which did not show non-compliance at the sampling sites in this study.

Principal components analysis

Initially to validate an analysis of principal components, a multiple dispersion diagram was performed, in order to visualize possible relationships among variables. In Figure 7, strong direct relationships between the variables SST and P, and P, OD and pH are identified. In contrast strong inverse relationships between SST and pH, SST and OD, P and OD, P and pH among others are shown

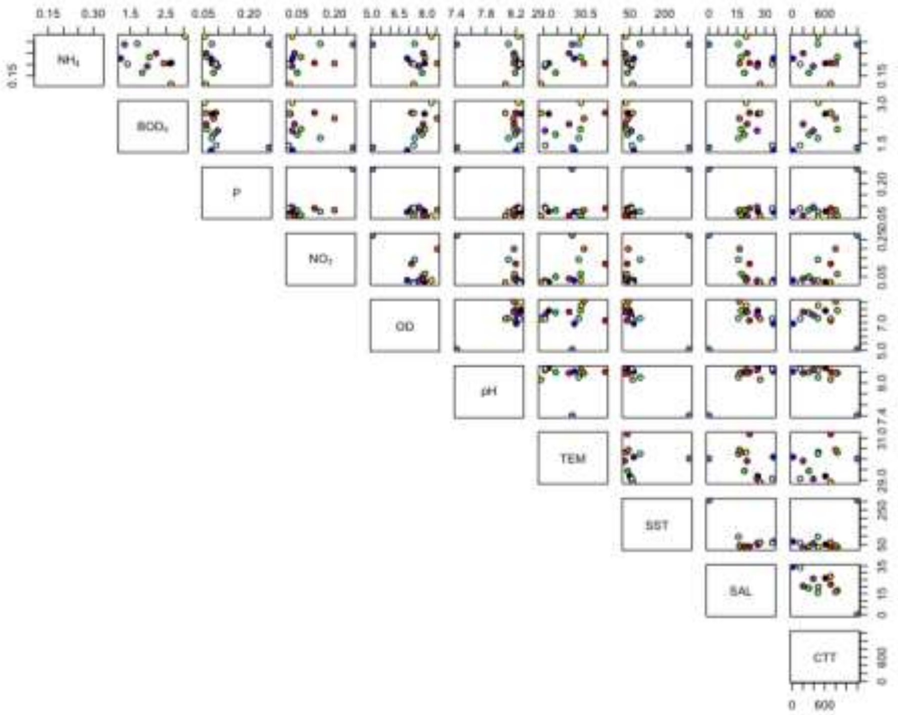

Figure7. Multiples cater plot

Table 2 shows the Pearson correlations between each pair of variables. The range of these correlation coefficients ranges from -1 to +1, and they measure the strength of the linear relationship between variables. From there, the follow significant relationships between variables may be obtained: DBO_5 - OD, P - NO_3^-, P - OD, P - pH, P - SST, P - SAL, P - CTT, NO_3^- - pH, NO_3^- - SST, NO_3^- - Sal, NO_3^- - CTT, OD - pH, OD - SST, pH - SST, pH - SAL, pH - CTT, SST - SAL, SST - CTT, SAL - CTT. This confirmed relationships between the variables, and the analysis of principal components could be performed.

Table 2. Correlations matrix

	NH_4^+	DBO_5	P	NO_3^-	OD	pH	TEM	SST	SAL	CTT
NH_4^+	1									
DBO_5	-0,08	1								
P	0,27	-0,47	1							
NO_3^-	0,37	-0,22	0,74	1						
OD	-0,16	0,59	-0,85	-0,49	1					
pH	-0,28	0,37	-0,91	-0,75	0,84	1				
TEM	0,53	0,16	0,05	0,51	0,01	-0,08	1			
SST	0,34	-0,49	0,95	0,72	-0,89	-0,96	0,01	1		
SAL	-0,48	0,03	-0,66	-0,83	0,39	0,75	-0,40	-0,66	1	
CTT	0,11	0,23	0,56	0,71	-0,34	-0,66	0,28	0,56	-0,76	1

Scree plot was used to identify the number of components with eigenvalues greater than unity. Figure8. shows three components that meet this criterion and these explain 88.08% of the total variance or the information contained in the original database.

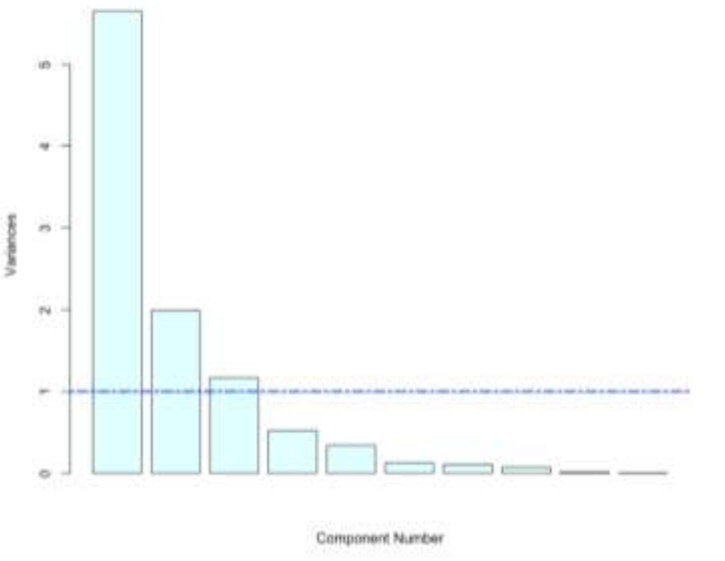

Figure8. Scree plot of eigenvalues

The values of loadings of each element of the components are depicted in table 4. For this study only variables with loadings greater than 0.5 were selected.

Table 3. Weights of variables by components

	Comp.1	Comp.2	Comp.3
NH_4	0,42	0,42	0,67
DBO_5	-0,38	0,68	-0,48
P	0,93	-0,24	-0,05
NO_3	0,87	0,30	-0,01
OD	-0,80	0,47	-0,07
pH	-0,96	0,14	0,13
TEM	0,27	0,75	0,41
SST	0,95	-0,26	-0,01
SAL	-0,83	-0,41	0,10
CTT	0,70	0,40	-0,54

Factor loadings may be classified as strong (> 0.75), moderate (0.75-0.50) and poor (0.50-0.30), although this classification also depends on the number of data available. Component 1 explains 56.5% of the variance and is strongly and positively contributed to by P, NO3, SST. CT Have a moderate contribution and Sal, OD and pH contribute to negatively. This component represents nutrient pollution from sources such as sewage, agricultural activities and industrial wastewater, and also represents pollution from natural causes such as runoff and soil erosion. Component 2 explains 19.91% of the variance and is moderately contributed to by BOD_5 and strongly by T, this component represents biochemical pollution caused by organic material from residential and industrial sectors. Component 3 (11.67% of varinacea) is positively contributed to by NH4 and negatively contributed to by CT both to a moderate level, these parameters are linked to anthropogenic factors such as discharges of untreated wastewater to the body of water. Components 2 and 3 are more related to anthropogenic pollution, while component 1 is contributed to by anthropogenic pollution and natural causes.

The objective of the cluster analysis (CA) is to gather objects (for this case sampling points) in aggregates based on their similarities and the interdependence of their physicochemical and microbiological characteristics. Although with Kruskal Wallis test a first approach was made by similarities between stations, showing differences among monitoring points by variable, the cluster analysis is definitive to differentiate the groups, taking into account the variation of all the variables in all the different stations. The cluster analysis produces a dendogram as shown in 12.

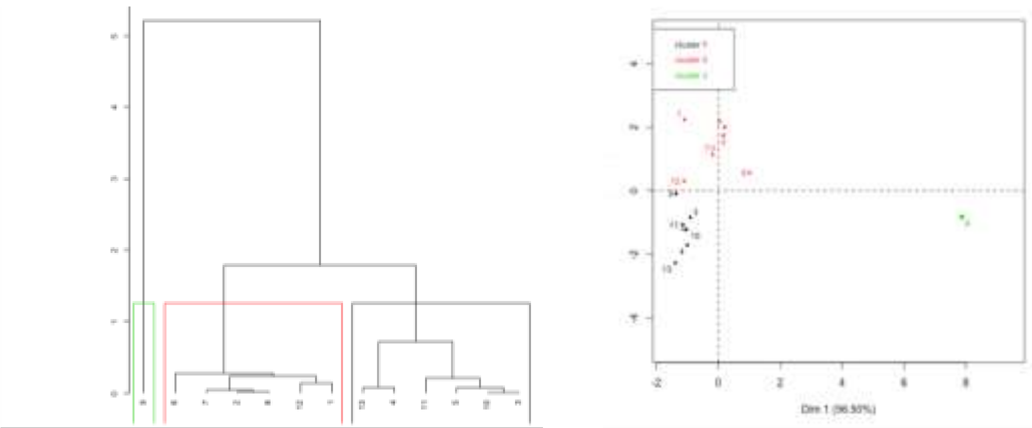

Figure 12.Dendogram based on agglomerative hierarchical clustering for all stations

The dendogram grouped the thirteen monitoring stations into three statistically significant clusters. The cluster 1 formed by stations P13, P4, P11, P5, P10 and P3, cluster 2 formed by P6, P7, P2, P8, P12 and P1 and cluster 3 formed only by P9.

Cluster 1 (P13, P4, P11, P5, P10 and P3) corresponds to relatively low contaminated stations, which are located in tourist and port areas, where the contribution of pollution is mainly by urban waste water, possible spills of boat fuel, etc. Moderately contaminated cluster 2 (P6, P7, P2, P8, P12 and P1), corresponds mainly to the industrial zone, these stations receive pollution by inefficient wastewater treatment plants of companies located in the industrial sector. Most of these companies (refineries, petrochemical plants, food processors, etc.) comply with law regulations but their effluents contain high levels of pollutants. The highly contaminated cluster 3 is located at the mouth of the DiqueCanal, which makes it a site with high natural and anthropogenic pollution, because it receives natural contributions of solids and fresh water from the Magdalena river and also receives pollutants from companies that are in its route, all these contributions deteriorated the quality of the resource at this point. Results obtained using CA might be used to reduce the number of parameters and/or stations in order to reduce the number of samples and the costs. For rapid quality assessment studies, number of the sampling sites could be reduced and only representative sites from each cluster identified by CA could be used[11,16].

Conclusions

In this study, surface water quality data for 10 parameters collected from 13 monitoring stations along Cartagena bay in Colombia from 2000 to 2017 were analyzed using multivariate statistical techniques. All the variables showed a non-normal distribution behavior, due to this Kruskal-Wallis test a non-parametric test was used to compare the spatial variability of parameters in all stations. Hierarchical cluster analysis grouped 13 sampling sites into three clusters of similar water quality characteristics, which may facilitate future monitoring of the water quality of Cartagena bay by reducing the number of sampling stations and associated costs. Factors obtained from PCA analysis indicate that the parameters responsible of water quality variations are mainly related to nutrients, dissolved oxygen, fecal and organic pollution (from industrial and domestic wastewater).

References

1. Wang Y, Wang P, BaiY, Tian Z, Li J, Shao X, Li B. L. Assessment of surface water quality via multivariate statistical techniques: A case study of the Songhua River Harbin region, China. Journal of Hydro-Environment Research.,2013, 7(1), 30–40.
2. Jagadeeswari B, Ramesh K. Water Quality Index For Assessment Of Water Quality In South Chennai Coastal Aquifer, Tamil Nadu, India. International Journal of ChemTech Research., 2012, 4(4), 1582-1588.
3. Ogwueleka T. C. Use of multivariate statistical techniques for the evaluation of temporal and spatial variations in water quality of the Kaduna River, Nigeria. 2015.
4. CarDique. (2015). CarDique. Retrieved August 1, 2015, from www.carDique.gov.co
5. Acevedo R, Severiche C. Identification of Di-Bromine-Mercury Resistant Bacteria Isolated from Sediments in Cartagena de Indias, Colombian Caribbean Beaches. Revista Avances Investigación En Ingeniería., 2013, 10(2), 73-79.
6. Severiche C, Baldiris I, Acosta J, Bedoya E, Castro I, Pacheco H. Multivariate Analysis of Water Quality in Rosario Islands National Park (Colombia). American Journal of Engineering Research., 2017, 6(6), 136-144.
7. Invemar. Informe del estado de los ambientes y recursosmarinos y costeros de Colombia: Año 2011. Serie de Publicaciones Seriadas No 8, 203.(2012).
8. Restrepo J, Park E, Aquino S, Latrubesse E. Coral reefs chronically exposed to river sediment plumes in the southwestern Caribbean: Rosario Islands, Colombia. Science of The Total Environment., 2016, 553(15), 316-329.
9. Acevedo R, Severiche C, Jaimes J. Bacteria resistant to antibiotics in aquatic ecosystems. Revista Producción Más Limpia., 2015, 15(2), 160-172.
10. Severiche C, Barreto A, Acevedo R. Effect Of Rainfall On Water Quality In The Big Swamp Of Santa Marta, Colombia. Revista Avances Investigación En Ingeniería., 2013, 10(1), 58-67.
11. Marinovic A, Ruzdjak D. Evaluation of river water quality variations using multivariate statistical techniques: Sava River (Croatia): A case study. Environmental Monitoring and Assessment.,2015, 187(4), 1–14.
12. Taoufik G, Khouni I, Ghrabi, A. Assessment of physico-chemical and microbiological surface water quality using multivariate statistical techniques: a case study of the Wadi El-Bey River, Tunisia. Arabian Journal of Geosciences.,2017, 10(7), 181.

13. Hajigholizadeh, M., &Melesse, A. M. (2017). Assortment and spatiotemporal analysis of surface water quality using cluster and discriminant analyses. Catena, 151, 247–258. https://doi.org/10.1016/j.catena.2016.12.018
14. Tosic, M., Restrepo, J. D., Lonin, S., Izquierdo, A., & Martins, F. (2017). Water and sediment quality in Cartagena Bay, Colombia: Seasonal variability and potential impacts of pollution. Estuarine, Coastal and Shelf Science. https://doi.org/10.1016/j.ecss.2017.08.013
15. Yoon, J., Bhatta, K., Rastogi, G., Muduli, P. R., Do, Y., Kim, D., …Joo, G. (2016). Application of multivariate analysis to determine spatial and temporal changes in water quality after new channel construction in the Chilika Lagoon, 90, 314–319.
16. Jung, K. Y., Lee, K.-L., Im, T. H., Lee, I. J., Kim, S., Han, K.-Y., &Ahn, J. M. (2016). Evaluation of water quality for the Nakdong River watershed using multivariate analysis. Environmental Technology & Innovation, 5, 67–82. https://doi.org/10.1016/j.eti.2015.12.001
17. Jiang, Y., Guo, H., Jia, Y., Cao, Y., & Hu, C. (2015). Principal component analysis and hierarchical cluster analyses of arsenic groundwater geochemistry in the Hetao basin, Inner Mongolia. Chemie Der Erde - Geochemistry, 75(2), 197–205. https://doi.org/10.1016/j.chemer.2014.12.002
18. Pati, S., Dash, M. K., Mukherjee, C. K., Dash, B., &Pokhrel, S. (2014). Assessment of water quality using multivariate statistical techniques in the coastal region of Visakhapatnam, India. Environmental Monitoring and Assessment, 186(10), 6385–6402. https://doi.org/10.1007/s10661-014-3862-y
19. Parga-Lozano, C. H., Marrugo-González, a. J., & Fernández-Maestre, R. (2002). Hydrocarbon contamination in Cartagena Bay, Colombia. Marine Pollution Bulletin, 44(1), 71–74. https://doi.org/10.1016/S0025-326X(01)00201-6
20. CIOH. (2017). Weather conditions in Cartagena de Indias. Retrieved September 12, 2017, from www.cioh.org.co
21. APHA, AWWA, WEF. Standard Methods for the Examination of Water and Wastewater. 22th Ed. American Public Health Association/ American Water Works Association/Water Environment Federation, Washington DC, USA, 2012.
22. Restrepo, J. D., Zapata, P., Dı, J. M., Garzo, J., & Garcı, C. B. (2006). Fluvial fluxes into the Caribbean Sea and their impact on coastal ecosystems : The Magdalena River , Colombia, 50, 33–49. https://doi.org/10.1016/j.gloplacha.2005.09.002
23. Kazi, T. G., Arain, M. B., Jamali, M. K., Jalbani, N., Afridi, H. I., Sarfraz, R. A., … Shah, A. Q. (2009). Assessment of water quality of polluted lake using multivariate statistical techniques: A case study. Ecotoxicology and Environmental Safety, 72(2), 301–309. https://doi.org/10.1016/j.ecoenv.2008.02.024
24. Zhao, J., Fu, G., Lei, K., & Li, Y. (2011). Multivariate analysis of surface water quality in the Three Gorges area of China and implications for water management. Journal of Environmental Sciences, 23(9), 1460–1471. https://doi.org/10.1016/S1001-0742(10)60599-2

*****