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SELECTION OF PARAMETERS IN THE DESIGN OF BEACH COASTAL WATER QUALITY MONITORING PROGRAMS

SELECCIÓN DE PARÁMETROS EN EL DISEÑO DE PROGRAMAS DE MONITOREO DE CALIDAD DE AGUAS COSTERAS EN PLAYAS

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ABSTRACT

Water quality analyses form an important part of a beach monitoring program in order to ensure the water's recreational adequacy, aesthetic value, and ecosystem health. While the inclusion of multiple water quality parameters in the program's design allows for comprehensive analyses, limiting the number of parameters included may be beneficial to balance costs and permit sufficient spatio-temporal sampling. In order to inform decision-making with regards to the selection of parameters, this study presents an analysis of the relationships between 16 water quality parameters, based on data collected from 61 beaches of the Caribbean and Pacific coasts of Colombia between 2001 and 2011. Correlation coefficients show moderate to very strong relationships among parameters related to water clarity (turbidity, transparency, total suspended solids) and among microbiological parameters, suggesting that the number of these parameters selected for monitoring could be reduced. In consideration of these results as well as other factors such as costs, technical complexity of analyses, and the identification of established reference values, it is recommended that a beach water quality monitoring program include as a minimum, the basic *in situ* parameters (temperature, salinity, pH and dissolved oxygen), one parameter related to water clarity (turbidity), and at least one microbiological parameter (Enterococos o *Escherichia coli)*. Selection of the specific parameters to be included will depend largely on the technical capacity to measure each parameter, the reference values identified for comparison, available financial resources, as well as the specific priorities and local characteristics of each beach.

KEY WORDS: Water quality, beach tourism, monitoring program

RESUMEN

El análisis de la calidad del agua es una parte importante de los programas de monitoreo de playas en busca de asegurar su aptitud para usos recreacionales, su valor estético y la salud del ecosistema. Mientras que la inclusión de múltiples parámetros de calidad de agua dentro del diseño del programa brinda un análisis comprensivo, la limitación del número de parámetros incluidos puede ser benéfica para equilibrar costos y permitir un muestreo espacio-temporal adecuado. Con el fin de apoyarla toma de decisiones en cuanto a la selección de parámetros, este estudio presenta un análisis de las relaciones entre 16 parámetros de calidad de agua, basado en datos colectados en 61 playas de las costas Caribe y Pacifica colombianas entre los años 2001 y 2011.Los coeficientes de correlación muestran desde moderadas hasta muy fuertes relaciones entre parámetros indicativos de claridad (turbidez, transparencia, sólidos suspendidos totales) y microbiológicos, sugiriendo que el número de estos parámetros seleccionados para monitoreo podría ser reducido. En consideración a estos resultados, junto con otros factores como costos, la complejidad técnica de análisis y la identificación de valores de referencia establecidos, se recomienda que un programa de monitoreo de calidad de aguas en playas incluya, como mínimo, los parámetros básicos *in situ* (temperatura, salinidad, pH y oxígeno disuelto), un parámetro indicativo de penetración lumínica (la turbidez) y al menos un parámetro microbiológico (Enterococos o *Escherichiacoli*). La selección de los parámetros específicos a incluir dependerá en gran medida de la capacidad técnica para su medición, los valores de referencia identificados para comparación, los recursos financieros disponibles, así como las prioridades y características locales de cada playa.

PALABRAS CLAVE: Calidad de agua, playas turísticas, programas de monitoreo

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INTRODUCTION

Water quality analyses are an integral part of an environmental monitoring program for touristic beaches, and in general, present important information for the management of the coastal zone (Ariza et al., 2007). Amongst the various human activities found in the coastal zone, beach tourism represents one of the most important uses, given its economic significance especially in the Caribbean (Vallega, 1999). However, the conservation of a beach's environmental quality may present challenges, as land-based activities can affect the coastal water quality, which in turn could have detrimental results on one or more of the services offered by the beach, such as its recreational adequacy, aesthetic value, or ecosystem health (ICONTEC, 2007; Jennings, 2004). Consequently, effective management of touristic beaches and their related environmental services requires an up to date knowledge of coastal water quality.

Adequate water quality is particularly important in terms of the water's sanitary properties, as recreational use of waters carries the critical responsibility of being safe for users, and thereby the risk of illness, though inputs of wastewater to the coastal zone can compromise the water's capacity for recreational use (Chalmers et al., 2000). The aesthetic quality of a beach is a factor closely linked with its value and popularity, and thus carries economic importance to the area, placing a high significance on the water's cleanliness and clarity. Conservation of marine and coastal ecosystems is also related to water quality, and given the services provided by ecosystems in a beach environment, such as touristic attractions, fisheries, and coastline protection, the water's capacity for the conservation of ecosystems should also be considered important for beach management.

A water quality monitoring program shouldinclude the analysis of various different parameters to report on a beach's recreational, aesthetic and ecosystem properties. A water body's adequacy for recreational use is commonly monitored with microbiological parameters, such as total coliforms, fecal coliforms (also known as thermotolerant coliforms), *Escherichiacoli*, and *Enterococci*, which are indicators of the presence of fecal matter and are related to the occurrence of human illness of bathers. The World Health Organization (WHO) recommends the use of *Enterococci* as an indicator of recreational quality (WHO, 2003), while current Colombian legislation cites total and fecal coliforms (MinSalud, 1984) as well as *Enterococci* (ICONTEC, 2007), as criteria for recreational use of a water body.

The aesthetic quality of a water body could be defined as the water's clarity, which can be characterized by a number of parameters, such as transparency, turbidity or total suspended solids (TSS). Measures of transparency using a secchi disk often depend on light availability and the vision of the person taking the reading, while analyses of turbidity and TSS are two different laboratory analyses that measure the amount of matter in the water which obstructs its clarity. The presence of petroleum hydrocarbons in the water would also reduce the aesthetic quality of the beach, due to their hindrance to water clarity and unnatural appearance, while they can also be harmful to marine organisms at high concentrations (Peters et al., 1997).

Indicators of eutrophication could also be included in the aesthetic category, as increased phytoplankton in the water column reduces the clarity of the water, and furthermore affects the color of the water, giving it a greenish tint which could be viewed as aesthetically undesirable to tourists (Boyd, 2000). Parameters used as indicators of eutrophication typically include chlorophyll-a, the nutrients nitrogen and phosphorus, as well as dissolved oxygen.

Parameters indicative of water quality with respect to ecosystem conservation could include all of the aforementioned parameters in the aesthetic category, as water clarity is a critical aspect of the photosynthetic processes of benthic ecosystems (Fabricius, 2005). Indicators of eutrophication are furthermore pertinent for ecosystem conservation as nutrient-rich waters may shift the ecological balance of coral reef ecosystems in the favour of macroalgal dominance (Lapointe, 1997) while eutrophic waters are limited in dissolved oxygen which is critical for marine organisms (Correll, 1998). Additionally, monitoring of the phsyico-chemical parameters dissolved oxygen, temperature, salinity and pH is important for ecosystem conservation as marine organisms are known to live within given ranges of these parameters, the divergence of which could lead to the hindrance of growth, mortality and an overall reduction in ecosystem services (Ellison and Fransworth, 1996; Hoegh-Guldberg, 1999; Koche et al., 2007; Thorhaug et al., 2006; Wild et al., 2011).

While monitoring of the aforementioned parameters would permit vigilance of a beach's recreational, aesthetic and ecosystem properties as related to water quality, the inclusion of all of these parameters in a monitoring program may not be feasible due to limitations in funding and time required for analyses. Likewise, other aspects of a monitoring program's design, such as the number of sampling stations and the frequency of sampling, may also be dependent on the availability of time and financial resources, and so the design of a monitoring program must take into consideration the specific priorities of a beach and make cost-effective decisions when selecting the parameters. Standards for the sustainable development of touristic beaches typically include the requirement of water quality monitoring,however, such standards may not include criteria for selecting parameters for such a monitoring program, as is the case of Colombian standards (ICONTEC, 2007).Selection amongst a set of parameters may include various criteria, such as the cost of analysis, the identification of established reference values to which to compare results, and the satisfaction of monitoring priorities (i.e. adequacy for recreational, aesthetic and ecosystem uses); in this context it is of the utmost importance that each parameter being monitored can successfully respond to management objectivesby use of an established threshold value with which an environmental authority can confidently state that the beach is adequate or inadequate for a particular use, such as recreation. The relationships present between parameters are also of importance, for example, should two parameters monitored for the same objective be closely related, it would not be cost-effective to include both in the monitoring program.

In order to inform decision-making with regards to the selection of parameters when designing monitoring programs for touristic beach water quality, this study presents an analysis of the relationships between 16 water quality parameters, based on data collected from beaches of the Caribbean and Pacific coasts of Colombia between 2001 and 2011.

MATERIALS AND METHODS

Water quality data analyzed for this study were collected as a part of the Monitoring Network for the Conservation and Protection of the Marine and Coastal Water Quality of Colombia (REDCAM, acronym in Spanish; INVEMAR, 2012). The REDCAM monitoring program has collected water samples twice annually, covering Colombia's dry season (February – April) and rainy season (August – November), since 2001 from nearly 360 stations along the Pacific and Caribbean coasts of Colombia. Samples are taken from the surface (25-30 cm depth) and analyzed for physico-chemical and microbiological parameters as well as contaminants, according to the methodologies of Garay et al. (2003).

For this study, biannual data from 2001-2011 were extracted from the REDCAM database for the 61 stations which represent touristic beaches of the Pacific and Caribbean coasts. These stations are located approximately 2 m from the coastline with depths of 1 these data were filtered to include 16 parameters, selected due to their use as indicators of sanitary, aesthetic and ecosystem quality (Table 1), including 11 physico-chemical parameters, 4 microbiological parameters, and the parameter dissolved and dispersed petroleum hydrocarbons (DDPH, also known as total aromatic hydrocarbons (TAH)). In order to evaluate the relationships between these parameters, Spearman correlation coefficients were calculated for each possible pairing of the 16 parameters from results of the 61 stations grouped as a collective, yielding an evaluation of 120 relationships between paired parameters (Conover, 1999). The Spearman correlation analysis was utilized due to the non-parametric nature of the data, as confirmed by a Shapiro-Wilks test ($p < 0.01$). While past reports suggest there to be differences in the water quality between stations and between seasons, this spatio-temporal variation would not limit the paired correlation analyses evaluated in this study, but rather provides a broader range of conditions over which to test the hypothesis of general relationships between parameters. For the purposes of this study, relationships between parameters were defined as poor, moderate, strong and very strong for correlation coefficients with magnitudes ranging between 0.0 – 0.24 (poor), 0.25 - 0.49 (moderate), 0.50 - 0.74 (strong), and 0.75 - 1.00 (very strong) (Martínez et al., 2009).

RESULTS

Results of the cross-correlation analysis showed both positive and negative relationships with magnitudes ranging between 0.0025 and 0.82 (Table 2). Of the 120 relationships analyzed between parameters, 22 relationships were shown to be moderate (0.25 – 0.49), one relationship was shown to be strong (0.50 – 0.74), and two relationships were shown to be very strong (0.75 – 1.00). All moderate, strong and very strong relationships were shown to be significant at the 95% level ($p < 0.05$).

Table 1: Parameters evaluated for inclusion in beach water quality monitoring programs, grouped by type of parameter and their use as indicators.

Group		Parameter	Code	Unit	Indicator
Physico-chemical	in situ	Dissolved Oxigen	DO	mg/L	Ecosystem
		pH	PH	-	
		Salinity	SAL	-	
		Temperature	TEM	°C	
	Nutrients	Ammonia	NH4	µg/L	Eutrophic (Ecosystem & Aesthetic)
		Nitrite	NO2	µg/L	
		Nitrate	NO3	µg/L	
		Orthophosphate	PO4	µg/L	
	Clarity-related	Total Suspended Solids	TSS	mg/L	Aesthetic
		Transparecny	TRA	m	
		Turbidity	TUR	NTU	
Petroleum Hydrocarbons		Dissolved and Dispersed Petroleum Hydrocarbons	DDPH	µg/L	
Microbiological		Thermotolerant coliforms	CTE	MPN/100 mL	Sanitary
		Total Coliforms	CTT	MPN/100 mL	
		Escherichia coli	ECO	CFU/100 mL	
		Enterococci	EFE	CFU/100 mL	

Table 2: Correlation coefficients calculated between each pair of parameters evaluated.

	DO	PH	SAL	TEM	NH4	NO2	NO3	PO4	TSS	TRA	TUR	DDPH	CTE	CTT	ECO	EFE
DO																
PH	0,15															
SAL	-0,10	-0,07														
TEM	0,08	0,06	-0,25													
NH4	-0,07	-0,03	0,04	-0,14												
NO2	-0,08	-0,14	-0,19	-0,05	0,25											
NO3	-0,05	-0,12	-0,12	-0,1	0,24	0,24										
PO4	0,01	-0,02	-0,14	-0,19	0,25	0,22	0,2									
TSS	-0,09	-0,16	0,09	-0,09	-0,02	0,06	0,04	0,16								
TRA	0,04	0,04	-0,33	0,20	-0,04	0,02	-0,12	-0,26	-0,45							
TUR	0,09	-0,07	0,02	-0,09	0,07	0,22	0,22	0,16	0,5	-0,08						
DDPH	-0,13	-0,01	0,24	-0,003	0,02	0,12	-0,04	0,07	0,13	-0,22	0,15					
CTE	-0,15	-0,08	0,13	-0,22	0,1	0,22	0,2	0,21	0,14	-0,26	0,43	0,20				
CTT	-0,12	-0,10	0,13	-0,23	0,11	0,22	0,22	0,19	0,09	-0,28	0,43	0,16	0,82			
ECO	0,01	0,05	0,09	-0,30	0,08	0,19	0,18	0,19	0,27	-0,31	0,36	0,01	0,46	0,43		
EFE	-0,09	-0,14	0,22	0,01	-0,02	0,18	0,18	0,08	0,12	-0,37	0,31	0,10	0,44	0,48	0,39	

Amongst physico-chemical parameters, poor relationships were found between the *in situ* parameters: dissolved oxygen, pH, salinity and temperature, with the exception of a moderate inverse relationship found between temperature and salinity (-0.25). Some of these parameters are physically dependent for which one might expect correlation coefficients to be higher, such as dissolved oxygen which is influenced by temperature and salinity (Chester, 1990), or salinity and pHwhich show relationships in mixing zones of freshwater with marine waters (Mosley et al., 2010). However, the results found would suggest that the relationships between these parameters are more complex than simple paired linear relationships. The influence of freshwater inputs is of particular importance for the relationship between salinity and pH, as Mosley et al. (2010) show that pH decreases at low salinities (0 - 2), increases at intermediate salinities (2 – 15) and then stabilizes at high salinities (>15).

Cross-correlations between the nutrients ammonia (NH_4), nitrite (NO_2), nitrate (NO_3) and orthophosphate (PO_4) yielded moderate relationships between NH_4 and PO_4 (0.25) and between $NH_4$and NO_2 (0.25), while other relationships between nutrients were shown to be poor. Dissolved nutrients continually interact in aquatic environments through processes of primary productivity but in marine waters, concentrations are typically low, such that land-based inputs can cause sharp increases in marine nutrient concentrations. The moderate relationships between NH_4 and PO_4andbetween NH_4 and NO_2 may be explained by inputs of wastewater which is typically high in these compounds.

The final group of physico-chemical parameters is of those related to the water's clarity: total suspended solids (TSS), transparency, and turbidity. Transparency showed very strong inverse relationships with turbidity (-0.80), while a strong relationship was found between TSS and turbidity (0.50). Though these measures are distinct, the magnitude of the correlation coefficients found show that they similarly reflect the water's clarity. Also grouped among indicators of aesthetic quality, the dissolved and dispersed petroleum hydrocarbons (DDPH) showed poor relationships with all of the other parameters.

Amongst the microbiological parameters, a very strong relationship was found between total coliforms and thermotolerant coliforms (0.82). As thermotolerant coliforms represent a subgroup of the total coliforms, in the case of this study the high correlation coefficient shows that a large proportion of the total coliforms detected were of the thermotolerant type, confirmed by the identification of 35% of the samples having equal values of total coliforms and thermotolerant coliforms, while amongst all samples the thermotolerant coliforms represented 57.4% of the total coliforms. Moderate relationships were also found between *Enterococci* and thermotolerant coliforms (0.44), total coliforms (0.48), and *E.coli* (0.39), as well as between *E.coli* and total coliforms (0.46) and thermotolerant coliforms (0.43). The co-occurrence of these microorganisms is expected given that they have a common source in domestic wastewater and are inhabitants of the gastrointestinal tracts of warm-blooded animals. *E. coli* also showed moderate correlations with TSS (0.27) and salinity (-0.30), while all of the microbiological parameters showed moderate inverse relationships with transparency and moderate positive relationships with TSS. These results may be related to the negative effect that increased salinity can have on aquatic microbiological concentrations (Gabutti et al. 2000; Ortega et al., 2009), and the positive effect that increased suspended matter (i.e. TSS) can have on the longevity of bacteria due to their adhesion to suspended particles or colloids, as well as the reduction of light which acts as a bactericide (Davies et al., 1995; Mallin et al. 2000).

DISCUSSION

Reducing the number of parameters included in a beach water quality monitoring program may be beneficial to balance costs and permit sufficient spatio-temporal sampling. In order to minimize the number of parameters included and still adequately report on a beach's recreational, aesthetic and ecosystem properties, parameters could be discarded from each of the groups evaluated when results are shown to be similar through moderate, strong or very strong relationships between parameters. Correlation coefficients reported in this study suggest that inclusion of one of the clarity-related parameters (TSS, transparency, and turbidity) and one of the microbiological parameters (total coliforms, thermotolerant coliforms, *E.coli*, *Enterococci*) may be sufficient given the similarity found between the parameters in each of these groups. In the case of microbiological parameters, it is also important to bear in mind that the parameter selected should adequately indicate the presence of pathogenic organisms, though in the case of total coliforms they are not directly associated with pathogens nor are they exclusively fecal in origin (Solo–Gabriele, 2000; Savitchtcheva y Okabe, 2006). However, it is important to also consider other factors in the selection of parameters such as costs, technical capacities for analysis, the specific priorities of the beach, and the identification of reference values with which to compare results.

In terms of costs, the *in situ* parameters are the least expensive of all. In comparison to the base cost of the *in situ* parameters, the costs of analyzing nutrients and clarity-related parameters is about twice as costly. Microbiological analyses are approximate 5-8 times as costly, while analyses of DDPH require a much greater investment being about 35 times more expensive.

The technical capacity of a laboratory for measuring these various parameters should likewise be evaluated before designing a monitoring program. Analyses of *in situ* parameters as well as SST and turbidity are relatively simple, while the measurement of transparency using a secchi disk is a simple procedure, the dependency of the result on the vision of the observer makes this method difficult to standardize. Though simple techniques exist for the measurement of nutrients (e.g.Hach), in marine waters the low concentrations found and the saline matrix require analytical techniques with higher degrees of complexity (Garay et al, 2003; Strickland y Parsons 1972). Analyses of microbiological parameters and DDHP are also relatively complex and require specific training (Garay et al, 2003).

The priorities of a monitoring program will vary depending on the beach. While sanitary properties which permit adequate recreational use of the waters is a high priority in any beach, the importance of a beach's aesthetic quality may depend on the beach as those located on coasts with strong wave action will naturally have waters of low clarity. Water quality objectives are based on the management goals which will help ensure that water quality supports the identified environmental values and associated uses. Each objective aims to protect an identified value. To assess whether the objectives are met, there are specified biological, toxicological or physico–chemical indicators and their numerical criteria. For instance, if an objective is to maintain or improve water quality so that it is suitable for primary contact recreation (the environmental value), then the presence of excessive bacteria could compromise the ability to achieve this, and so the bacterial indicator levels in the water must be kept below a specified value (ANZECC, 2000). It is also important to consider the location of nearby sources of pollution for each of the beaches (e.g. wastewater input, river outlets, industrial discharges) when selecting parameters in the design of a beach water quality monitoring program (WHO, 2003).

The identification of established reference values is of great importance to the analysis of the data collected. *In situ* parameters typically have well established reference values through legislation (e.g. MinSalud, 1984) and literature on coastal ecosystems (e.g. Ellison and Fransworth, 1996; Hoegh-Guldberg, 1999; Koche et al., 2007; Thorhaug et al., 2006; Wild et al., 2011). On the other hand, in can be quite difficult to establish reference values for nutrients and clarity-related parameters, as baseline levels of these parameters vary widely depending on local coastal hydrodynamic conditions and terrestrial inputs, among other factors. In terms of DDPH, while a reference value of 10 µg/L has been identified by Atwood et al. (1988), this value established under conditions of contaminated waters in the Gulf of Mexico may be too high for comparison in most touristic beaches. However, one must take into account beaches that are in close proximity to areas of hydrocarbon storage and transportation.

In the case of microbiological parameters, a number of established reference values are available for comparison. However, in this case the selection of the parameter to be monitored and the reference value to which to compare results may be of great importance with respect to the results reported. To illustrate the importance of this selection, microbiological water quality data used in this study were compared to reference values for adequate recreational use (primary contact) defined by Colombian legislation for thermotolerant coliforms (200 NMP/100mL; MinSalud, 1984) and those defined by the World Health Organization (WMO, 2003) as minimal risk levels for *Enterococci* (40 CFU/100mL) and substantial risk levels for *Enterococci* (200 CFU/100mL). Results showed that 30.3% of data surpassed the value of MinSalud (1984), 19.3% of data were above the minimal risk value of WHO (2003), while only 7.6% of data surpassed the substantial risk value of WHO (2003). This example shows the great influence the selection of a parameter and its reference value can have on results, emphasizing the importance of the design of a beach water quality monitoring program and its relation with coastal zone management. In this regard there are two important aspects to bear in mind; firstly, the reference values defined by Colombian legislation were based on studies done in other countries due to the lack of current epidemiological studies in Colombia´s tropical waters which relate the presence and behavior of microorganisms with the acquisition of illness (Gonzalez et al., 2003; Salas, 2000). Secondly, as described by Shibata et al. (2004), microbiological water quality data will to some extent depend on the elements of its measurement, and given that microbiological indicators only provide information on part of the microbiological environment as a whole, to employ a single group of microorganisms could mask situations of pollution, putting bathers at risk.

CONCLUSIONS

The optimization of the financial resources and time available to a beach water quality monitoring program require balanced decision-making with respect to the parameters included, the number of sampling stations and the frequency of sampling. Based on the results of this study, it is recommended to include all 4 of the *in situ* parameters evaluated (temperature, salinity, pH and dissolved oxygen) given their low cost, simplicity of measurement, availability of reference values, importance for ecosystem preservation and poor relationships found in correlation coefficients between these parameters, resulting from varying environmental conditions in each beach (e.g. River input, hydrodynamic conditions, etc.).

Amongst clarity-related parameters (TSS, transparency and turbidity), given the correlation coefficients found it is recommended to select 1 of the 3 parameters, depending on the technical capacities available to the monitoring program. The recommended parameter would be turbidity, given that measures of transparency can be subjective and TSS in beaches can be influenced by factors other than water clarity, such as large particles resuspended by wave action, while turbidity measures the average scattering of light by suspended particles and is thus more indicative of the water´s overall clarity.

Given the costs and complexity of measuring hydrocarbons and nutrients in marine waters, as well as the lack of established reference values, it would be beneficial to exclude these parameters from a beach monitoring program, unless a potential heavy influence has been identified, such as petroleum transport and storage zones or sources of wastewater, respectively. Priorities to report on the ecosystem and aesthetic qualities of the beach may be covered by the simpler *in situ* and clarity-related parameters.

In terms of microbiological parameters, it is strongly recommended to include at least one parameter in a monitoring program, and perhaps two parameters (Enterococos o *Escherichia coli)* given the high priority placed on sanitary control. However, the similarity shown in the results of these parameters suggest that measurement of all four parameters evaluated would not be cost-efficient.

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