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Analysis of the influence of natural factors on the bathing condition of beaches in the cities of Garopaba, Imbituba and Laguna, in the state of Santa Catarina – Brazil

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ABSTRACT

The degradation of bathing conditions is a problem that has increased and generated international concern. Water from natural environments, when used for recreation, can bring a series of risks to those who come into contact, mainly because of the presence of pathogenic microorganisms in aquatic ecosystems. In Brazil, the National Environment Council regulated Resolution number 274 of 2000, which provides for bathing conditions. The main parameter to be investigated is the microbiota characteristic of domestic sewage, such as thermotolerant coliforms, *Escherichia coli* or *enterococci*. The possibility of influencing natural factors in modifying water quality in coastal regions is also highlighted. Therefore, the objective of this work is to evaluate, through statistical methods, the influence of natural factors on the bathing conditions of the beaches in the cities of Garopaba, Imbituba and Laguna – Santa Catarina, Brazil - from January 2010 to December 2019. Although factors such as the population increase, characteristic of summer, cause a great impact on water quality, factors such as the intensity of rain and variations in tides showed a significant influence on the bathing conditions of these beaches, as demonstrated by the statistical tests used in that study.

Keywords: Statistical analysis, correlation, Spearman, Kruskal-Wallis, significance.

Análise da influência de fatores naturais na condição de balnabilidade das praias dos municípios de Garopaba, Imbituba e Laguna, no estado de Santa Catarina - Brasil

RESUMO

A degradação das condições balneares é um problema que tem aumentado e gerado preocupação internacional. A água de ambientes naturais, quando utilizada para recreação, pode trazer uma série de riscos a quem entra em contato, principalmente pela presença de microrganismos patogênicos nos ecossistemas aquáticos. No Brasil, o Conselho Nacional do Meio Ambiente regulamentou a Resolução nº 274 de 2000, que dispõe sobre as condições de banho. O principal parâmetro a ser investigado é a microbiota característica do esgoto doméstico, como coliformes termotolerantes, *Escherichia coli* ou *enterococos*. Destaca-se também a possibilidade de influenciar fatores naturais na modificação da qualidade da água nas regiões costeiras. Portanto, o objetivo deste trabalho é avaliar, por meio de métodos estatísticos, a influência de fatores naturais nas condições de banho das praias dos municípios de Garopaba, Imbituba e Laguna - Santa Catarina, Brasil - no período de janeiro de 2010 a dezembro de 2019. Embora fatores como o aumento populacional, característico do verão, causam grande impacto na qualidade da água, fatores como a intensidade das chuvas e as variações das marés tiveram influência significativa nas condições de banho dessas praias, conforme demonstrado pelos testes estatísticos utilizados em aquele estudo.

Palavras-chave: Análise estatística, correlação, Spearman, Kruskal-Wallis, significância.

Introduction

The term bathing is directly linked to the quality of water bodies that have the purpose of recreation to the human being, with direct contact of the same for long periods of time (Silva et al., 2019; CETESB, 2020). There are some factors that interfere with the quality of water in coastal regions, which may be of natural or anthropic origin. Among the natural factors, there is the occurrence or not of precipitation, the circumstance of the tide, the presence of water bodies that flow towards the sea and the physiographic characteristics of the beach. Valentini et al. (2021a), investigated the influence of natural factors on the bathing conditions of Itapoá-SC beach, and they noted, for example, that precipitation causes a significant influence on the bathing conditions of this beach. Anthropic factors, on the other hand, may be related to the occurrence of domestic and / or industrial effluent discharge in nearby regions (or that flow into the coast), in addition to the population increase caused in high season periods (CETESB, 2020).

The degradation of bathing conditions is a problem that has increased and generated international concern, worrying the public because of the risk to human health due to the poor quality of natural water for recreational use, which has grown in recent years. Water from natural environments, when used for recreation, can bring a series of risks to those who come into contact, mainly because of the presence of pathogenic microorganisms in aquatic ecosystems. Currently, many beaches have been closed because the bathing is not in accordance with the current regulations, which assess the condition of bathing in relation to the presence of pathogenic microorganisms (Hirai et al., 2016; Huang et al., 2017).

Thus, to monitor the beaches and ensure recreation for bathers, especially in high season, the National Environment Council (CONAMA) regulated Resolution No. 274 of 2000, an instrument created to assess water quality, in relation to the established levels for the bathing of Brazilian waters, establishing guidelines and criteria in order to ensure the ideal conditions for use for recreational purposes (Brazil, 2000). According to this resolution, sampling should preferably be performed during periods of high peak tourists in the collection region, as the population increase intensifies pollution due to the increase in the generation of domestic effluents in the vicinity (CETESB, 2019). The main parameter

to be investigated is the occurrence, above the permitted level, of a microbiota characteristic of domestic sewage. For this, the existence of fecal coliforms (thermotolerant) or *Escherichia coli* or *enterococci* (for marine regions) at monitoring points for a period of five weeks is evaluated (CONAMA, 2000).

Therefore, monitoring water quality is an important tool to ensure bathing (Corbari et al., 2016). It is worth mentioning the possibility of the influence of natural factors in the modification of water quality in coastal regions. For example, the work of Aguilera, Gershunov and Benmarhnia (2019) on the influence of Atmospheric Rivers on coastal water quality in the California region demonstrated the relevant influence of high precipitation on the incidence of fecal microbiota at the collection points, due to the increase in diffuse pollution caused by runoff. In the study by Arnold et al. (2017), who evaluated the incidence of diseases, including those originating from fecal pathogens, in surfers in the San Diego region, California, showed the highest occurrence of this type of disease after periods of intense rainfall.

Many studies have evaluated the impact of intense rainfall events on coastal water quality and correlated them with water quality parameters Corbari et al. (2016), because intense rain events corroborate the transport of pollutants and pathogenic microorganisms from land to sea water. In addition, overloaded sewage collection systems, when faced with intense rains, also contribute to the transport of pollutants and contaminants to the beach water (Aguilera et al. 2019).

In turn, in the work published by Lima, Crété and Barrella (2016) on the influencing agents in the bathing of the beaches of Santos, São Paulo, showed a small relationship between the phenomenon of tides and precipitation with the amount of *enterococci* found in the data evaluated. As well as the study by Barroso (2019), this evaluated the bathing of beaches on the north coast of Rio Grande do Sul, and pointed out the lack of relevance of rainfall in altering data regarding the amount of thermotolerant coliforms in the samples.

Monitoring programs for sea water quality usually work with a large amount of data, which is why it is often difficult to specifically investigate the available information. Therefore, methods are needed to simplify the large amount of data and enable a better interpretation (Franklin et al., 2018). One possibility for a better study and interpretation of data is the use of multivariate statistical methods, which have recently been widely used.

For example, the work carried out by Lima, Crété and Barrella (2016) used Pearson's correlation coefficient to correlate the factors they studied in relation to the bathing of the beaches in Santos-São Paulo, as well as the authors Zhou et al. (2016) who performed a correlation analysis between land use and occupation and water quality. In turn, a study by Katarzyte, Vaiciute and Nasvytis (2019) used the Kruskal-Wallis statistical method to analyze the variation in water quality of different beaches.

Application of statistical techniques can be considered a valuable tool for water management resources, helping to identify possible sources of pollution. Recently, several other studies have used statistical analysis as a tool for monitoring water resources as well as for a better understanding of the processes responsible for changing the water quality, not only regarding bathing conditions. Studies developed by Valentini et al. (2021b) and Santos et al. (2020) performed statistical procedures, such as, correlation and variance analysis to evaluate the parameters applied in the calculation of Water Quality Index (WQI) in the Mirim Lagoon Hydrographic Basin and stream Morreira-Fragata, respectively.

The coastal region of Brazil encompasses approximately 9,000 km in length, with distinct characteristics and extreme geological and ecosystemic richness (Klein and Short, 2016). In the south of the country, there are the beaches that comprise the territory of the state of Santa Catarina, formed by 922 km in length between open coast and coastlines, covering 246 sandy beaches (Klein, Short and Bonetti, 2016). Among the municipalities in the south of the state, there are Garopaba, Imbituba and Laguna, located in a tourist region known as "Southern Enchantments" (Barros e Nakazone, 2020). The mentioned municipalities suffer great tourist pressure in periods of high season and are contemplated by the qualitative monitoring of the bathing in points spread by its beaches and coastal regions (Cristiano et al., 2018; Munari et al., 2018; Santos et al., 2019).

Therefore, the main objective of this work is to evaluate, through statistical methods, the influence of natural factors, such as tidal variations and rain intensity, on the bathing conditions of the

beaches of the cities of Garopaba, Imbituba and Laguna in the State from Santa Catarina, Brazil. Furthermore, the present study aims to show that statistical analyses are very suitable tool for this kind of evaluation. In addition, statistical analyses possibly to assess the influence of natural factors on the bathing conditions of the beaches studied here.

Data and Methods

Study Area

Belonging to the great Hydrographic Basin of the South Atlantic, the study area took place on the southern coast of the state of Santa Catarina, more specifically, on the coast of the municipalities of Garopaba, Imbituba and Laguna (Figure 1). These municipalities have increasingly been the destination of a significant number of tourists, making this activity fundamental in their economic development (Santos et al., 2010; Soller and Castrogiovanni, 2014; Quiroga et al., 2014).

It is worth mentioning that on the coast of these municipalities there is an Environmental Preservation Area (APA) of the Baleia Franca (Figure 1), created by Federal Decree on September 14, 2000. It covers an area of 156,100 hectares and its objectives are to protect the inlets with the highest concentration of right whales with young, in addition to land areas such as dunes, wetlands, rocky shores and lagoons (Bellotto and Sarolli, 2008).

In all, data from 17 collection points were analyzed (Figure 1) from January 2010 to December 2019, through reports available on the Institute of the Environment (IMA) website. The number of points per municipality, the spa where the collection takes place and their respective coordinates, obtained through the Google Earth program with the geodetic reference system WGS 84, are shown in Table 1.

To obtain Figure 1, free open source software known as QGIS, version 3.12.02 was used. The figure was associated with the SIRGAS 2000 reference system.

Figure 1. Location of municipalities and collection points.

Table 1. Collection points.

County	Spots	Balneary	Coordinates	
			Coordinates (S)	Coordinates (W)
Garopaba	GA1	Garopaba Beach	28°01'23.9"	48°36'51.4"
	GA2		28°01'20.8"	48°37'07.6"
	GA3	Siriú Beach	27°58'29.1"	48°37'41.6"
Imbituba	IM1	Rosa's Beach	28°08'06.9"	48°38'32.8"
	IM2	Ibiraquera Beach	28°09'14.1"	48°39'12.9"
	IM3		28°09'23.9"	48°39'09.1"
	IM4	Ribanceira Beach	28°11'24.3"	48°39'44.8"
	IM5	Porto Beach	28°13'01.4"	48°39'58.0"
	IM6	Vila Nova Beach	28°14'40.5"	48°39'39.3"
	IM7		28°16'00.7"	48°40'57.3"
Laguna	LA1	Itapirubá Beach	28°20'30.0"	48°42'27.2"
	LA2	Gi's Beach	28°27'55.0"	48°45'57.3"
	LA3	Mar Grosso's Beach	28°28'53.5"	48°45'57.0"
	LA4	Cabeçudas' Lagoon	28°26'25.3"	48°49'12.4"
	LA5	Teresa's Beach	28°31'29.5"	48°45'46.1"
	LA6	Cardoso's Beach	28°36'26.8"	48°49'18.6"
	LA7	Farol's Beach	28°36'08.6"	48°48'56.6"

Source: IMA (2020).

Data Obtaining

The data for Tides, Rainfall Intensity and E.coli were obtained through weekly and monthly reports available on the Institute of the Environment (IMA) website. Created in 2017, replacing the Foundation of the Environment (Fatma), IMA is currently the environmental agency at the state level of the Government of Santa Catarina responsible for monitoring the

bathing of water in various resorts along the state's coast (IMA, 2020). The variation of parameters and / or units is shown in Table 2.

Table 2. Parameters used for the study.

Parameters	Variations and/or units		
Tide	Ebb	Flood	Low
Rainfall	Absent	Weak	Moderate
E.Coli	NMP/100ml		

Bathing Conditions

IMA makes available, together with the aforementioned data, the condition of bathing at which each location where the collections took place according to CONAMA Resolution N°. 274 of 2000. The condition to which these collection points are classified, according to this resolution occurs as follows:

Proper: When in 80% (or +) of a set of samples collected in the previous 5 weeks in the same place, there is a maximum of 800 *Escherichia coli* per 100 milliliters.

Improper: When more than 20% of a set of samples collected in the previous 5 weeks in the same location is greater than 800 *Escherichia coli* per 100 milliliters or when, in the last collection, the result is greater than 2000 *Escherichia coli* per 100 milliliters.

Statistical Analysis

In order to assess the correlations of the variables studied with the bathing condition, a matrix of the significance of these correlations was used. This matrix brings the p-values to assess whether the null hypothesis will be accepted or rejected by this test. For this test, the null hypothesis (H0) is that there is no significant effect of the variable on the result of bathing and for $p < 0.05$ this hypothesis is rejected.

To find out if the data analyzed in this study are compatible with the type of correlation coefficient to be used, it was first necessary to test the normality of these data. For data that follows a normal distribution, for example, Pearson's

coefficient is the most commonly used, whereas for data that do not have a normal sample, nonparametric coefficients such as the Spearman Rhô coefficient, also known as the Spearman coefficient (Guimarães, 2017). To prove or reject the normality of the data in this study, the Kolmogorov-Smirnov (K-S) and Shapiro-Wilk (S-W) tests were used with a 95% confidence interval and a significance level of 0.05.

Another statistical test used here, in order to verify whether there is significant variability in the bathing condition in relation to changing tides or the intensity of rain, was the Kruskal-Wallis non-parametric test. In general, this test aims to assess whether there is in fact a statistically significant variation in bathing in relation to variations in tide and rain intensity or whether the variation in bathing, in relation to these factors, is relative to deviations random.

In this test, the null hypothesis (H0) is that there is no significant variation for the stipulated factor, that is, for those parameters that, using a 5% significance level, obtain a p-value less than 0.05, the null hypothesis is rejected and its variability is considered significant for the predefined factor.

Results and discussions

Firstly, the K-S and S-W normality tests were applied to assess their sample distribution. Both tests, as shown in Table 3, resulted in p-values < 0.05 rejecting the null hypothesis that assumed a normal distribution. With this result, we must proceed with a correlation matrix with Spearman's coefficient.

Table 3. Normality tests

	K-S Test			S-W Test		
	P – values (sig.)					
	Garopaba	Imbituba	Laguna	Garopaba	Imbituba	Laguna
Tide	0,000	0,000	0,000	0,000	0,000	0,000
Rainfall Intensity	0,000	0,000	0,000	0,000	0,000	0,000
E. coli	0,000	0,000	0,000	0,000	0,000	0,000
Bathing Conditions	0,000	0,000	0,000	0,000	0,000	0,000

Shrestha and Dorevitch (2019), in their study which quantified E. coli for Lake Michigan

beaches in Chicago, also applied the K-S normality test to their E. coli data. As in this study, the sample

distribution found was not normal. The use of non-parametric tests, such as those used in this study, to assess the assumptions of sample distribution of data is something quite consolidated in the literature and several authors have used these tests in studies related to water quality. Furthermore, the KS and SW normality tests are applied in several studies regarding surface or groundwater quality (e.g., Santos et al., 2020; Batista et al., 2021; Leite et al., 2021; Valentini et al., 2021c; Valentini et al., 2021d; Silveira et al., 2021). Santos et al. (2021), for example, applied KS and SW tests for evaluate data sampling distribution of in order to know which correlation coefficient would be more appropriate for application of correlation analysis between these data and Water Quality Index calculated in their study. Furthermore, other studies can be cited for corroborating the importance of analyzing the sample distribution and the amplitude to which normality tests were used in the

studies conducted by Drose et al. (2020) and Valentini et al. (2020) that, in turn, applied KS test to confirm a normality distribution of the data set studied they studied followed a normal distribution. Moreover, normality distribution of the data is a prerequisite for carrying out Principal Component Analysis performed in their studies.

As for the correlations of the variables tide, rain intensity, and E. coli, their significance can be seen in Table 4. As noted, the tide variable has a significant correlation with the bathing of the beaches in the city of Laguna, while the variable intensity of rain, in turn, and bathing have a significant correlation on the beaches of the cities of Garopaba and Imbituba. The E. coli variable has a significant correlation with the bathing capacity of the three cities, as was already expected, since the condition of bathing in these cities is assessed precisely by the concentration of E. coli.

Table 4. Analysis of the significance of correlations with Spearman's coefficient

	Sig. (bilateral) of correlation		
	Garopaba	Imbituba	Laguna
Tide	0,360	0,691	0,001
Rainfall Intensity	0,000	0,001	0,194
E. coli	0,000	0,000	0,000

According to Vicente (2017) and CETESB (2018), the influence that occurred on the beaches of Laguna between tide and bathing can be justified by the fact of the moment of collecting samples in the changing rooms. If, at the time of collection, the tide is flooding, the large volume of affluent water can block potentially contaminated water courses that flow into the sea and, in addition, may favor the dilution of sewage present in the waters of the beaches. If it is leaking, the opposite occurs, there will be the drainage of water from streams to the sea, taking a greater amount of contaminants to the beaches. According to Lima, Crété and Barrella (2016), water samples collected in the sea after the occurrence of rains show great contamination, which may explain the influence between rain intensity and bathing for the cities of Imbituba and Garopaba. Furthermore, Valentini et al. (2021a), evaluating the influence of natural factors on the bathing conditions of the Itapoá-SC beach, also found a significant correlation between rainfall intensity and bathing conditions of this beach.

Regarding the variation of the bathing condition in relation to the predefined factors (tide and rain intensity), their significance, assessed by the Kruskal-Wallis test, can be seen in Table 5. As shown, the variable tide obtained p-value <0.05 for the cities of Garopaba and Laguna, which means that the condition of the beaches in these cities suffers, in fact, significant variation according to the variation of the tide. As for the variation in bathing in relation to the variation in rainfall intensity, this was considered significant for the beaches in the cities of Garopaba and Imbituba. It is worth mentioning that the rains are one of the main causes of the deterioration of the water quality of the beaches, among various debris, such as sewage and garbage, which are carried to the beaches by systems of galleries, streams and even drainage channels (CETESB, 2018; Aguilera, Gershunov and Benmarhnia, 2019).

Several studies have used variance tests in order to assess whether the variation of a certain parameter or factor really causes a significant change in the analyzed data. This type of analysis

can be performed for a wide variety of data, whether they are related to the presence of chemical substances in the water, related to the bathing conditions of the beaches or any other parameter of interest. Valentini et al. (2021e), for example, applied the non-parametric test of Kruskal-Wallis to assess the variation in water quality between the monitoring points studied in the Mirim Lagoon Hydrographic Basin. Gao et al. (2021), in turn, used the ANOVA variance test to analyze whether there was significant seasonal variation (winter – summer) in the concentration of microplastics in seawater and sediments on the beaches of Qingdao city, China. Regarding the influence of natural factors on bathing conditions, Valentini et al. (2021a) noted in Itapoá-SC beach, based on data from 2010 to 2019, the tide variation did not cause a significant influence on the bathing conditions, but the rainfall intensity, as observed by these authors, in fact had a significant effect on the bathing condition of this beach.

It should also be noted that the analysis of significance presented here measures only if the variation was significant or not, it does not measure the intensity of that variation. The intensities of these variations, in seasonal percentages, can be seen in Figures 2, 3 and 4 and in tables 6, 7 and 8.

As shown in Figure 2, with regard to the city of Garopaba, the highest percentages of beaches unsuitable for swimming were found at low tide and in the condition of intense rain, as well as in the summer season, followed by the autumn season. Looking at Table 6, it is possible to see that the seasons with the highest levels of intense rain and low tide were, respectively, the autumn and summer seasons, corroborating the graphs shown in Figure 2. The fact that summer has a higher percentage of unsuitable beaches it is also due to the increase in the number of people visiting these beaches.

Table 5. Significance of the variation of the bathing condition in relation to the variation of tide and intensity of rainfall

		Kruskal-Wallis' Test	
		Factors	
		Tide	Rainfall intensity
		p-value (Sig.)	
Bathing conditions	Garopaba	0,022	0,000
	Imbituba	0,651	0,001
	Laguna	0,004	0,140

Figure 2. Percentage variation of bathing in relation to tide, rain and season in the city of Garopaba.

Table 6. Tide percentages and rain intensity by season for the city of Garopaba.

Season	Tide (%)				Rainfall intensity (%)			
	Flood	Ebb	Low	High	Absent	Weak	Moderate	Intense
Summer	39,67	50,41	4,13	5,79	49,31	27,55	13,50	9,64
Autumn	54,32	34,57	7,41	3,70	49,38	20,99	13,58	16,05
Winter	48,81	44,05	3,57	3,57	69,05	10,71	13,10	7,14
Spring	48,77	44,26	2,87	4,10	61,07	21,31	15,16	2,46

Figure 3. Percentage variation of bathing in relation to the tide, rain and season in the city of Imbituba.

Table 7. Percentage of tide and intensity of rainfall per season for the city of Imbituba.

Season	Tide (%)				Rainfall Intensity (%)			
	Flood	Ebb	Low	High	Absent	Weak	Moderate	Intense
Summer	31,65	33,56	27,83	6,96	50,20	23,60	18,96	7,23
Autumn	41,76	21,76	24,71	11,76	51,18	23,53	15,29	10,00
Winter	46,00	17,00	24,00	13,00	66,50	13,00	16,50	4,00
Spring	38,46	33,33	18,38	9,83	70,94	12,61	9,83	6,62

In Figure 3, it can be seen that, for the city of Imbituba, the highest percentages of beaches unsuitable for swimming were found at low tide and, again, in the condition of intense rain. Keeping the seasonal relationship already presented in Garopaba, the city of Imbituba had a higher percentage of unsuitable beaches in summer and autumn, respectively.

Next, Figure 4 shows that, in relation to Laguna beach, the highest percentages of beaches with improper bathing conditions occurred at low tide and, like Garopaba and Imbituba, in conditions

of intense rain. Again, the season with the most unsuitable beaches for swimming was summer, followed by autumn.

As can be seen in Tables 7 and 8, for the beaches of the cities of Imbituba and Laguna, the tide that was most observed in the summer was the ebb and the rainfall condition of that season was intense rain. This, coupled with the fact that in the summer there is a greater concentration of tourists in beach towns, corroborates the observed fact that summer is the season with the highest percentage of beaches unsuitable for swimming.

Figure 4. Percentage variation of bathing in relation to tide, rain and season in the city of Laguna.

Table 8. Percentage of tide and intensity of rain by season for the city of Laguna.

Season	Tide (%)				Rainfall Intensity (%)			
	Flood	Ebb	Low	High	Absent	Weak	Moderate	Intense
Summer	33,10	25,96	31,87	9,07	50,55	20,05	21,98	7,42
Autumn	34,15	23,17	25,00	17,68	48,78	18,90	20,73	11,59
Winter	41,49	19,15	29,26	10,11	73,40	9,57	13,30	3,72
Spring	41,45	24,79	25,21	8,55	69,02	10,90	13,68	6,41

Conclusions

Based on the results obtained by this study, it can be concluded that natural factors such as changes in the tide and the intensity of the rain can also influence the bathing conditions of the beaches. It is known, of course, that the limiting parameter for the analysis of bathing for the beaches studied here was the concentration of *E. coli*, however, as raised by this study, natural factors can influence this concentration. For example, heavy rains can carry pollutants from the streets and avenues of cities to the sea and certain tides can make it difficult to disperse these pollutants, reducing self-purification.

Still, it can be concluded that it was possible to use the statistical methods proposed here to assess the influence of such factors on the bathing, which highlights the importance of using these methods. When corroborating the possibility of using statistical methods for this type of analysis, this study brings a new possibility of approach for beach city managers about the environmental conditions of their beaches, since the use of statistical methods can make it easier for data analysis, assisting in the control and monitoring of water quality.

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