



Analytical Hierarchy Process Based Model for Safety Assessment of Coastal Touristic Locations

Alberto Daniel Dávila-Lamas^(✉), José J. Carbajal-Hernández,
Luis P. Sánchez-Fernández, and César A. Hoil-Rosas

Centro de Investigación en Computación, Instituto Politécnico Nacional,
Juan de Dios Bátiz s/n, Nva. Industrial Vallejo, 07738 Ciudad de México,
Gustavo A. Madero, Mexico
addavlam@gmail.com, {jcarbajalh, lsanchez}@cic.ipn.mx,
cesarhoil_92@hotmail.com

Abstract. Touristic Mexican beaches are highly visited places where safety is one of the most important priorities. In this work, a computational model based on the Analytical Hierarchy Process is proposed to evaluate main coastal characteristics, providing a safety index score. Parameters such as: wind, tide, temperature and bathymetry are studied using an importance weighment procedure. Beaches located at La Paz, South Baja California, Mexico are measured, and assessed to show the proposed model performance, providing a good alternative to impulse tourism.

Keywords: Analytical Hierarchy Process · Signal processing · Tourism · Safety · Beach

1 Introduction

Tourism is one of the fastest growing industries worldwide, and coastal areas are the most important sources of income. In Mexico, 73% of the economic income associated with tourism comes from beach areas [1]. Despite the attractive beach conditions for tourism, natural events such as red tide or sea conditions, could avoid the development of touristic activities. At present, there are no metrics to define if the coastal conditions are adequate for the practice of tourism activities. Actions to define security in coastal tourist areas are based only on monitoring tide by color coding. It is necessary to create tools to identify undesirable situations and places unsuitable for tourism. Annually, a large number of accidents are reported in tourist coastal zones due to the lack of safety signs, and the lack of knowledge of tourists to interpret signs when they exist. In this sense, warning signs do not reflect the real safety conditions present in the zone.

Some studies have carried out evaluations of coastal areas from different perspectives. Leatherman in 1992 [2] presented a comparison of beaches, evaluating quantitatively 50 physical, biological and human parameters that influence beach quality using the Leopold approach [3], which was originally designed for the evaluation of rivers scenery. Another quantitative assessment is presented in [4], taking into

consideration 5 relevant beach parameters (safety, water quality, facilities, scenery and litter) in the region of Andalucía, Spain. In this work, one of the evaluated parameters is safety; however, this indicator is formed from subjective observations of the evaluator, such as safe environment beach and infrastructure features, considering the possibility of area access with emergency vehicles. Both of these works qualify the data obtained from subjective observations; therefore, the preferences and perspectives of the evaluator influence the results.

Coastal landscape assessment has been the object of study by some researchers. In Ergin [5], 26 parameters have been defined to evaluate coastal scenery through surveys of tourists and landscape perception experts in Turkey and UK. For each parameter, 5 range of values or attributes were established. All parameters are integrated to perform a general assessment using a Fuzzy Logic Approach (FLA), to overcome the subjectivity and uncertainty detected in other models. In another paper, Ergin [6] presents the results obtained by the methodology in a particular application case by comparing 34 coastal zones in the Western Black Sea region.

Due to the lack of quantitative evaluations of coastal security, the generation of an index is necessary to allow the identification of undesirable situations and places unsuitable for tourist activity. The purpose of this paper is to design a computational model to assess ideal zones in beaches, where tourists can perform their activities with the best possible safety. This model is based on geographical characteristics, natural events, and physical factors, such as tide and wind. The beach safety depends on several factors, but the ones just mentioned above are the most relevant in order to generate an evaluation. The Analytical Hierarchy Process (AHP) methodology is used to assign the relative importance of each parameter. A FLA is proposed to calculate the safety index, since it has proven to overcome uncertainty and subjectivity.

This paper considers La Paz Bay as a case study; this tourist destination is located on the east coast, south of Baja California peninsula, in Mexico. La Paz City is located on the south of the bay and is the capital of Southern Baja California State. Due to the presence of the city in the bay, there are a large number of sensors monitoring different physical, chemical and biological parameters constantly. Additionally, some researchers have characterized the Bay seabed [7]. Some of this data and infrastructure is taken to feed the evaluation model. Parameters selected for analysis were bathymetry, wind, tide, temperature and a biological index.

In Sect. 2 we define the coastal characteristics. In Sect. 3 we present the model building. In Sect. 4 we give results. In Section we describe the conclusions.

2 Coastal Characteristics

Commonly, touristic beaches should have some recommendations about safety for tourists. Different criteria have been defined to generate areas for touristic activities and are represented by a set of parameters, which is the study case of this work. According to this, the following sections explain the needed information about the main characteristic of a touristic coast.

2.1 Geographic Site

La Paz is a popular tourist destination with a hot, dry climate located in the coordinates 24.14222, -110.31083. Beaches of this destination are the main attraction, with turquoise waters ideal for swimming, sun-bathing, enjoyable scenery and the practice of aquatic sports. Facilities provide information about weather and ocean measurements, and closeness of different touristic places are ideal for this study purpose. Figure 1 shows the geographic characteristics of the sampling site.

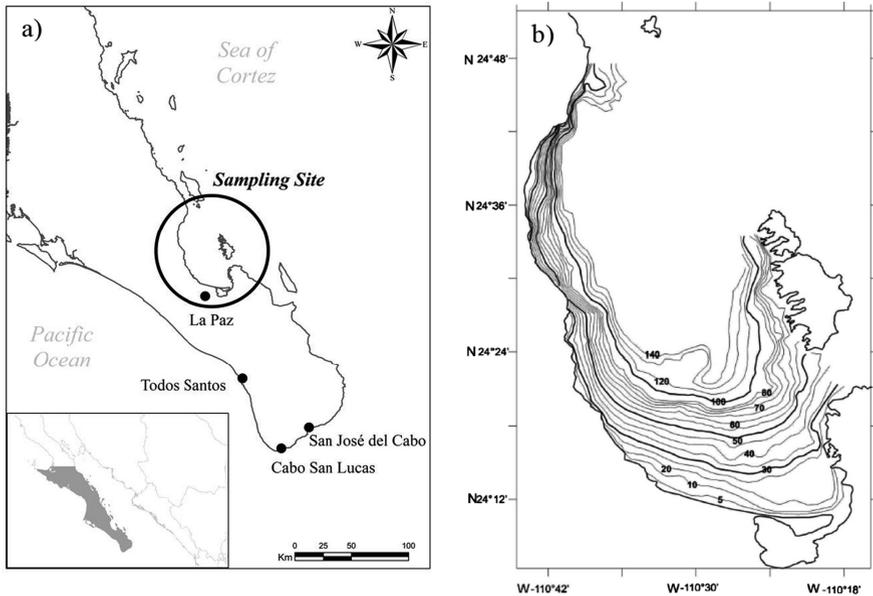


Fig. 1. (a) Sampling site monitored in La Paz Bay, located at Southern Baja California, Mexico. (b) Bathymetry measurements obtained from Del Monte in 2005 [8].

2.2 Factor Analysis

Usually, a problem depends on several factors, where involved parameters have different importance according to their behaviors and characteristics. This paper considers 3 principal factors to assign the importance of the parameters. The first factor is *measurement facility*; some parameters are difficult to quantify or require a previous processing. The next considered factor is the *dangerousness*; the risk associated to each parameter is not equal for all the parameters. The last factor is *infrastructure facilities*; data obtained from other sources could be obtained to feed the evaluation model. Factors are identified as follows:

- *F1*: Measurement facility
- *F2*: Dangerousness
- *F3*: Infrastructure facilities

The safety index proposed is functioned in 4 parameters, which were defined as the most relevant in this discipline according to the factors just mentioned. These parameters are: bathymetry, tide, temperature and wind speed. The first two parameters are associated with the risk of drowning [9–11], and the last are associated with the presence of red tide.

A classification for all the parameters is presented in Table 1. This classification is based on the international scales and information collected from other research works [12–14]. The categories defined in Table 1, include the different types of status present in beach locations dedicated to tourism; all measurements performed can be classified by one optimal range.

Table 1. Permissible limits defined for safe oceanographic parameters.

Safety parameters	Categories	Optimal range	Units	Fuzzy limits			
				<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>
Wind (<i>s</i>)	Calm	7–22	knots	7	13	17	22
	Light breeze						
	Breeze						
Tide (<i>d</i>)	Slight	0–2.5	Meters	0	0	0.5	2.5
	Moderate						
	Rough						
Temperature (<i>t</i>)	Tempered	26–30	°C	25	28	28	31
	Warm						
Bathymetry (<i>b</i>)	Exposed	0–2.5	Meters	0	0	2.5	6
	Very shallow						
	Shallow						

3 Model Building

3.1 Fuzzy Inputs

The purpose of the fuzzy assessment is to evaluate each parameter according to its own scale and optimal level, transforming the measured values into a [0–1] range. This normalizes all parameter ranges and scales [15]. To make this transformation, fuzzy expressions were created for each parameter, *d* refers to tide, *b* refers to bathymetry, *s* refers to wind and *t* refers to temperature; the expressions are defined as follows:

$$\mu(d) = \max\left\{ \min\left(1, \frac{2.5 - x}{2.5 - 0.5}\right), 0 \right\} \tag{1}$$

$$\mu(b) = \max\left\{ \min\left(1, \frac{5 - x}{5 - 2.5}\right), 0 \right\} \tag{2}$$

$$\mu(s) = \max \left\{ \min \left(\frac{x - 7}{13 - 7}, 1, \frac{22 - x}{22 - 17} \right), 0 \right\} \tag{3}$$

$$\mu(t) = \max \left\{ \min \left(\frac{x - 25}{28 - 25}, 1, \frac{31 - x}{31 - 28} \right), 0 \right\} \tag{4}$$

3.2 AHP Model

The safety evaluation on beaches can be defined according to the importance of each oceanographic involved parameter. For this purpose, an analysis of parameters with high impact in the safety assessment and the reasons why they are important are analyzed as proposed. This work uses the Analytic Hierarchy Process methodology, created by Saaty [16]. In the AHP, a relative importance level is assigned to each parameter according to Table 2.

Table 2. Importance scale interpretation according to Saaty [18].

Scale	1	2	3	4	5	6	7	8	9
Importance	Equal	Weak	Moderate	Moderate+	Strong	Strong+	Very	Very+	Extreme

The first step is to create a pairwise matrix ($A = a_{ij}$) where the importance priorities given by Saaty [15] can be assigned between parameters (w_a/w_b). This is a positive reciprocal $n \times n$ matrix and is constructed as follows:

$$A = \begin{matrix} & P_1 & P_2 & \cdots & P_n \\ \begin{matrix} P_1 \\ P_2 \\ \vdots \\ P_n \end{matrix} & \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} & = & \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \end{matrix} \tag{5}$$

The eigenvector proposed by Perron in 1907 [17] must be computed to determine the priority weights that will be used for computing the Safety index (SI). According to this, the square matrix **B** must be computed as follows:

$$B = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \times \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{6}$$

The sum of the rows is determined according to:

$$C_i = \sum_{j=1}^n B_{ij} \quad \forall i = 1, 2, \dots, n \tag{7}$$

The priority weights are obtained by normalizing the C_i vector according to:

$$W_i = \frac{C_i}{\sum_{j=1}^n C_j} \quad \forall i = 1, 2, \dots, n \tag{8}$$

An additional criteria step is to validate the matrix consistency as follows:

$$CR = \frac{\lambda_{max} - n}{(n - 1)RI} \tag{9}$$

where λ_{max} is the maximum eigenvalue of the pairwise matrix, n is the matrix size, CR is the Consistency Ratio and RI is the Random Consistency Index (Table 3) [18]. The calculation of the Consistency rate evaluates the confidence level inconsistencies found in the pairwise matrix building. A limit of $CR = 0.1$ was defined as the maximum acceptable inconsistency.

Table 3. Random consistency index.

Matrix size	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

3.3 Safety Index

The Safety Index (SI) is a value in a [0–1] range and is defined by involving the complete parameter assessments. Importance weights define the negative impact of each parameter, generating a score concerning the good or bad safety in that place. The SI index can be described as follows:

$$SI = \sum_{i=1}^n \mu_i(k)W_i^k \tag{10}$$

where k refers to a parameter, W is the i^{th} importance weight obtained in the AHP process and $\mu_i(k)$ is the fuzzy value obtained with the expressions defined in Sect. 3.1. By replacing each parameter in Eq. (10), then we have the following expression:

$$SI = \mu(t)W^t + \mu(d)W^d + \mu(b)W^b + \mu(s)W^s \tag{11}$$

where t refers to temperature, d refers to tide, b refers to bathymetry and s refers to wind.

If beach safety conditions are optimal, the index has a score of “1”; otherwise, when one or more parameters present non optimal values, the final score decreases, being “0” in the worst case.

4 Results and Discussions

4.1 Parameter Assessment

Based on expert criteria, comparisons between factors and parameters related to safety assessment were defined. Table 4 shows comparisons between factors, comparing them according to the importance scale and criteria defined for safety impact. Pairwise matrix uses the fractional values to compute the weights. Normalized columns can be used as a partial solution for weight assignment; however, the largest eigenvalue has been demonstrated to be the most accurate solution in the AHP. Tables 5, 6 and 7 have the respective pairwise matrices of each parameter, where comparisons were made taking into consideration the factor as decision criteria. Consistency ratios show values in acceptable levels.

Table 4. Factor comparison with a CR = 0.04501.

Factors	F1	F2	F3	Normalized	Eigenvector
F1	1	1/9	1/2	0.0709	0.0738
F2	9	1	8	0.7917	0.8044
F3	2	1/8	1	0.1374	0.1218
		Column sums	1		1

Table 5. Parameter comparative according to measurement Facility and with a CR = 0.09217.

Parameters	Tide	Temp	Wind	Depth	Normalized	Eigenvector
(d) Tide	1	1/8	1/3	3	0.1135	0.0897
(t) Temp	8	1	4	9	0.5599	0.6385
(s) Wind	3	1/4	1	7	0.2863	0.2295
(b) Bathymetry	1/3	1/9	1/7	1	0.0403	0.0423
			Column sums		1	1

Table 6. Parameter comparative considering Dangerousness and a $CR = 0.06174$.

Parameters	Tide	Temp	Wind	Depth	Normalized	Eigenvector
(d) Tide	1	9	7	1	0.4302	0.44
(t) Temp	1/9	1	1/3	1/9	0.0372	0.0403
(s) Wind	1/7	3	1	1/7	0.1024	0.0797
(b) Bathymetry	1	9	7	1	0.4302	0.44
				Column sums	1	1

Table 7. Parameter comparative considering Infrastructure facilities and a $CR = 0.09454$

Parameters	Tide	Temp	Wind	Depth	Normalized	Eigenvector
(d) Tide	1	5	3	1/5	0.2465	0.2027
(t) Temp	1/5	1	1/3	1/9	0.0441	0.0457
(s) Wind	1/3	3	1	1/7	0.1199	0.0942
(b) Bathymetry	5	9	7	1	0.5895	0.6574
				Column sums	1	1

The final weight priorities are obtained by combining all particular results according to the sum of the weight multiplication, having a global sum of the unity, which means that weights are balanced. Table 8 shows these results.

Table 8. Parameter comparative considering all factors and weights.

Parameter Factors	Parameter				Factor weights	Parameter			
	<i>d</i>	<i>t</i>	<i>s</i>	<i>b</i>		<i>d</i>	<i>t</i>	<i>s</i>	<i>b</i>
F1	0.0897	0.6385	0.2295	0.0423	0.0738	0.007	0.047	0.017	0.003
F2	0.44	0.0403	0.0797	0.44	0.8044	0.354	0.032	0.064	0.354
F3	0.2027	0.0457	0.0942	0.6574	0.1218	0.025	0.006	0.011	0.08
Final score					1	0.386	0.085	0.092	0.437

4.2 Safety Index Assessment

The safety index (SI) calculation was made over a database of collected measurements at sampling site. This database includes values of temperature, wind speed, tide and bathymetry. It has 976 samples, taken every 15 min from the 1st to 11th of January 2016. Figure 2. shows the parameter behavior in the corresponding sampling period.

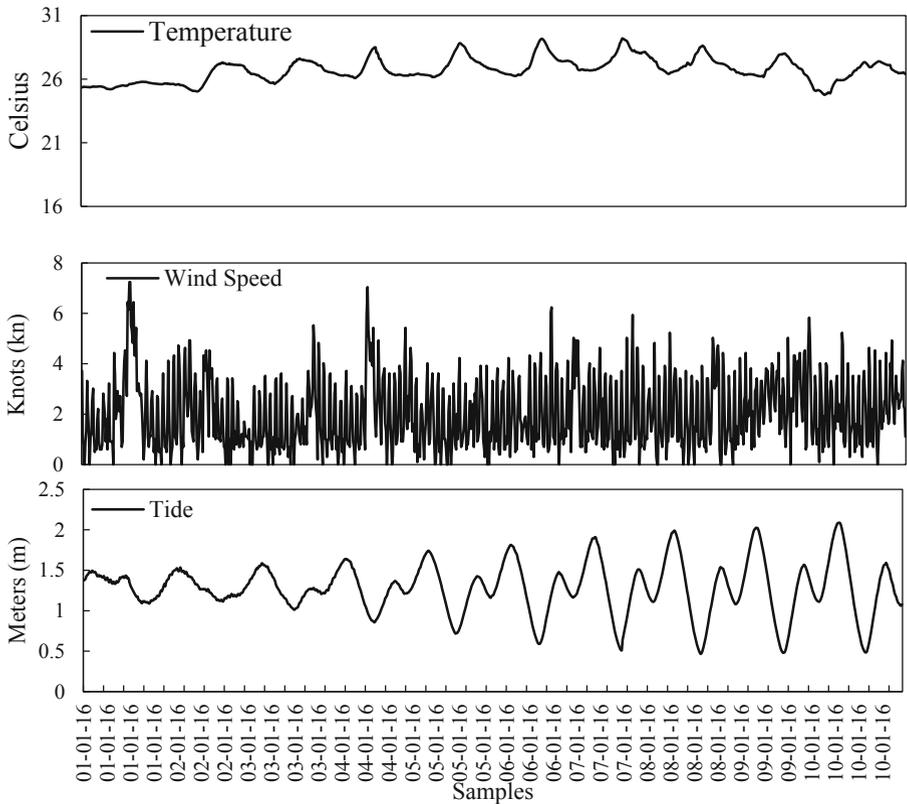


Fig. 2. Parameter signals used for safety assessment.

As can be seen in Fig. 2, wind conditions are out of the optimal ranges described in Table 1, so the probability of red tide presence increases, and this condition will affect the SI score. The temperature presented a highly variable behavior. The height of the waves increased over time, but never reaching values out of the optimal ranges. According to Fig. 1, the bathymetry area is estimated considering zones lower than 5 m depth, since deeper zones are not adequate for touristic practices. Parameter behaviors can be observed in Fig. 3, where the SI index assessment is performed.

Variations in temperature and wind speed can be observed; however, those changes, have not a significant influence in the safety index response. Tide variations largely affect the behavior of the index, due to the tide weight obtained in the AHP process is significantly higher than the rest of the parameters. The safety index variations were from 0.10 to 0.47 with a medium value of 0.28. This means that the safety conditions during the test dates, in the sampling site were bad.

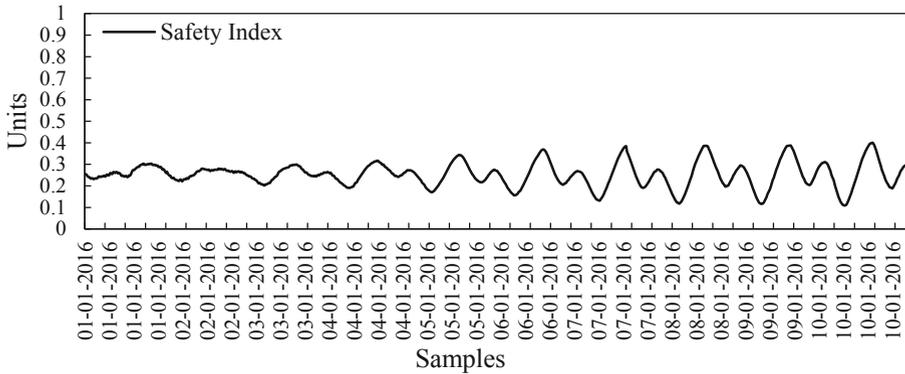


Fig. 3. Safety assessment using the SI index proposed at the sampling site.

Actually, there are no similar metrics for safety assessment on beaches found in literature, and all evaluations are made by subjective judgements. Our proposal had the aim of assessing safety locations according to physical parameters that can be measured and studied in an objective way, integrating oceanographic data in a computational model to evaluate beach safety. Result reports for the SI index show a new framework for identifying good or bad places for safe tourism at Mexican beaches. This characteristic is the most important strategy of local governments trying to obtain more tourists as a way to increase the economy of the region.

5 Conclusions

The safety index presented in this paper evaluates the beach safety conditions present at La Paz Bay, considering temperature, wind speed, bathymetry and tide. According to Literature, similar models have been developed in order to evaluate visual characteristics; however, our proposal has been developed in order to provide information about excellent or bad places for touristic activities on beaches. This tool is a novelty approach for assessing safety in touristic coastal locations; helping people to avoid risk areas, preventing accidents and increasing safety in touristic beaches. Although this research studied a Mexican place, it can be used for assessing another beaches by only replacing input data with those of the interest place. As a future work, more parameters have been proposed to be studied and analyzed such as: harmful wildlife, solar radiation or ocean aspects, integrating other techniques and computational models for better analysis to improve touristic care.

References

1. Banco de México: Extracto del Reporte sobre las Economías Regionales Enero – Marzo, pp. 10–13 (2018). <http://www.banxico.org.mx/>
2. Leatherman, S.P.: Beach rating: a methodological approach. *J. Coast. Res.* 253–258 (1997)

3. Leopold, L.B.: Quantitative Comparison of Some Aesthetic Factors Among Rivers, vol. 620. US Geological Survey (1969)
4. Micallef, A., Williams, A.T., Gallego Fernandez, J.B.: Bathing area quality and landscape evaluation on the Mediterranean coast of Andalusia, Spain. *J. Coast. Res.* 87–95 (2011)
5. Ergin, A., Karaesmen, E., Micallef, A., Williams, A.T.: A new methodology for evaluating coastal scenery: fuzzy logic systems. *Area* **36**(4), 367–386 (2004)
6. Ergin, A., Özölçer, İ.H., Şahin, F.: Evaluating coastal scenery using fuzzy logic: application at selected sites in Western Black Sea coastal region of Turkey. *Ocean Eng.* **37**(7), 583–591 (2010)
7. Urcádiz-Cázares, F.J., Cruz-Escalona, V.H., Nava-Sánchez, E.H., Ortega-Rubio, A.: Clasificación de unidades del fondo marino a partir de la distribución espacial de los sedimentos superficiales de la Bahía de La Paz, Golfo de California. *Hidrobiológica* **27**(3), 399–409 (2017)
8. Del Monte-Luna, P., Arreguín-Sánchez, F., Godínez-Orta, L., López-Ferreira, C.A.: Batimetría actualizada de la Bahía de La Paz, Baja California Sur, México. *CICIMAR Oceanías* **20**(1–2), 75–77 (2005)
9. Castelle, B., Scott, T., Brander, R.W., McCarroll, R.J.: Rip current types, circulation and hazard. *Earth Sci. Rev.* **163**, 1–21 (2016)
10. Drozdowski, D., et al.: Surveying rip current survivors: preliminary insights into the experiences of being caught in rip currents. *Nat. Hazards Earth Syst. Sci.* **12**(4), 1201–1211 (2012)
11. Drozdowski, D., Roberts, A., Dominey-Howes, D., Brander, R.: The experiences of weak and non-swimmers caught in rip currents at Australian beaches. *Aust. Geogr.* **46**(1), 15–32 (2015)
12. Alonso Rodríguez, R.: Hidrología y condiciones ambientales que determinan la proliferación de dinoflagelados causantes de marea roja en la Bahía de Mazatlán, Sin., México (2004)
13. Rodríguez, L.: Revisión del fenómeno de Marea Roja en Chile. *Rev. Biol. Mar.* **21**, 173–197 (1985)
14. Kim, D.I., et al.: Effects of temperature, salinity and irradiance on the growth of the harmful red tide dinoflagellate *Cochlodinium polykrikoides* Margalef (Dinophyceae). *J. Plankton Res.* **26**(1), 61–66 (2004)
15. Gutiérrez, J.D., Riss, W., Ospina, R.: Lógica Difusa como herramienta para la bioindicación de la calidad del agua con macroinvertebrados acuáticos en la sabana de Bogotá - Colombia/Application of fuzzy logic as bioindication tool for the water quality with aquatic macroinvertebrates in the Sabana de Bogotá-Colombia. *Caldasia* 161–172 (2004)
16. Saaty, T.L.: Decision making with the analytic hierarchy process. *Int. J. Serv. Sci.* **1**(1), 83–98 (2008)
17. Perron, O.: Grundlagen für eine Theorie des Jacobischen Kettenbruchalgorithmus. *Math. Ann.* **64**, 11–76 (1907)
18. Saaty, T.L.: Decision making—the analytic hierarchy and network processes (AHP/ANP). *J. Syst. Sci. Syst. Eng.* **13**(1), 1–35 (2004)