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### ENVIRONMENTAL RISK AT THE PUCUSANA'S ARTISANAL FISHING WHARF

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#### ABSTRACT

The study addresses the environmental risks in the AFW (Artisanal Fishing Wharf) Pucusana, in Lima-Peru, through an analytical, retrospective, and longitudinal study. Its objective was to evaluate the probability and consequence of the existing significant risks to define measures that control their effects in the environmental field during its operation, it focused on natural environment and socioeconomic indicators. The information collected was obtained at the landing stage and in entities related to its management (Pucusana Municipality, Pucusana Fishermen's Guild, General Directorate of Captaincies and Coast Guards, National Fisheries Development Fund, and Ministry of Production), through surveys, interviews and visits over a period of six months. Data from water quality monitoring in the Pucusana bay, carried out by DIGESA and IMARPE, were considered. The determinations of environmental risks were made based on the Environmental Risk Assessment Guide. The wharf presented an average environmental risk level of 42.67%, which is classified as Moderate; being the levels of risk in the natural and socioeconomic environments of 48% and 37.33%, respectively. Based on these results, the Pucusana AFW warrants taking control measures.

Keywords: Pucusana, environmental risks, Artisanal Fishing Wharf.

## **RESUMEN**

El presente estudio aborda los riesgos ambientales en la AFW Pucusana, Lima-Perú, con un enfoque analítico, retrospectivo y longitudinal. Su objetivo fue evaluar la probabilidad y consecuencia de los riesgos significativos existentes para definir medidas que controlen sus efectos en el ámbito ambiental durante su operación, se enfocó en indicadores del medio natural y socioeconómicos. La información recogida se obtuvo en el desembarcadero y en las entidades relacionadas con su gestión (Municipalidad de Pucusana, Cofradía de Pescadores de Pucusana, Dirección General de Capitanías y Guardacostas, Fondo Nacional de Desarrollo Pesquero, Ministerio de la Producción), mediante encuestas, entrevistas y visitas a lo largo de seis meses. Se consideraron los datos del monitoreo de la calidad del agua en la bahía de Pucusana, realizado por DIGESA e IMARPE. Las determinaciones de los riesgos medioambientales se hicieron basándose en la Guía de Evaluación de Riesgos Medioambientales. El desembarcadero presentaba un nivel medio de riesgo medioambiental del 42,67%, que se clasifica como Moderado, siendo los niveles de riesgo en los medios natural y socioeconómico del 48% y el 37,33%, respectivamente. Basándose en estos resultados, el AFW Pucusana justifica la adopción de medidas de control.

Palabras clave: Pucusana, riesgo ambiental, pesca artesanal.

## **I. INTRODUCTION**

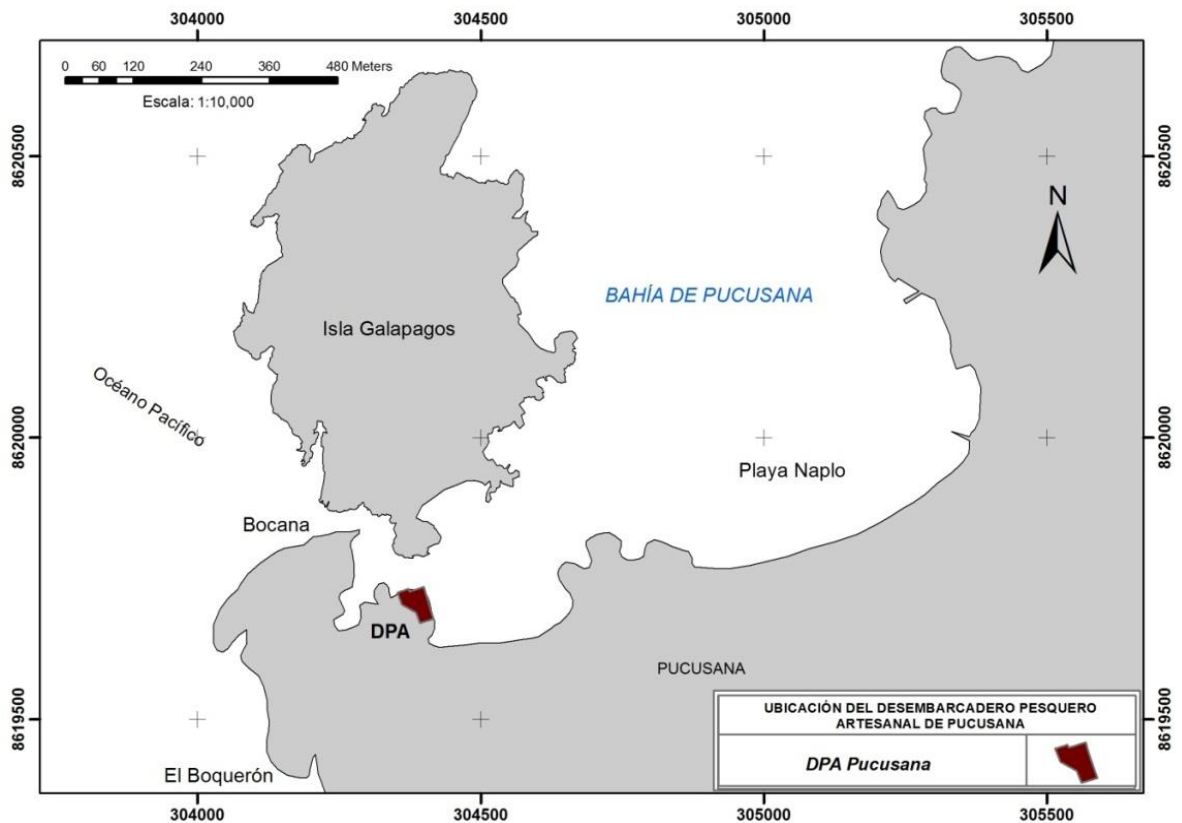
In the different activities that take place in a wharf, the people who perform them are exposed to high risks, which if not identified lead to losses that include people, equipment, materials and the environment. These manifestations are present in our reality and in particular at the site of the proposed study. The magazine "Nuestro Puerto Limpio Pucusana" (Our Clean Port Pucusana) identified the existence of chemical contamination caused by oil filters and batteries, in addition to a large amount of garbage accumulated on the seabed (Austermühle, 2002). In addition, an article was published on the bad odor and contamination of Pucusana Bay and the lack of wastewater treatment, which has a negative impact on the fauna, landscape, neighbors and tourists visiting the bay (Diario La República, 2012). Subsequently, Pucusana beach has been classified as unhealthy (DIGESA, 2012), a situation that is not unrelated to what happens in other AFW's and in order to support the improvement of environmental management at the national level, MINAM published the Environmental Risk Assessment Guide, as a guidance tool for specialists or evaluators of the Regional Governments, with the support of the sectors involved with the sole objective of standardizing guidelines and criteria for the estimation of environmental risk during an environmental assessment.

The objective of this study was to evaluate the probability and consequences of the environmental risks existing in the AFW Pucusana, in order to define measures to control their effects on the environment, caused by its activities in the period 2005-2012.

## II. MATERIALS AND METHODS

### 2.1 LOCATION OF THE STUDY

The non-experimental research work was carried out at the Artisanal Fishing Wharf (AFW) of Pucusana, ( $\phi$  12°28'48" S,  $\lambda$  76°47'58" W) located in the district of Pucusana, province of Cañete, Lima region (Figure 1).



**Figure 1.** Location of Pucusana AFW

### 2.2 MATERIALS

The study was developed under an analytical and retrospective modality with longitudinal data.

#### 2.2.1 RULES AND REGULATIONS

The following documents contributed to orient and establish a logical order of work in the determination of environmental risks, constituting orientations and guides for the achievement of the objective of this study.

- National Protocol for Quality Monitoring in Natural Surface Water Bodies (2011). Considered in the diagnosis of water quality and in the determination of monitoring points.
- Environmental Risk Assessment Guide (2011). Used in the identification of environmental hazards, analysis, and evaluation of environmental risks.

- Environmental Quality Standards (EQS) for Water (2017). Used in the analysis and interpretation of results, in natural and socioeconomic environments.

### **2.3 METHODS**

The method was based on the fishing activity developed in the Pucusana AFW, the sequence of which is described below.

#### **2.3.1 DATA COLLECTION IN THE FIELD**

One visit per week was made during a two-month period, gathering information on environmental risk activities at the Pucusana AFW.

In the first and second visits, the entities related to the AFW were contacted. This was followed by an identification of the study field, the surrounding beach and the AFW, observing the fishermen's workday and the activities at the wharf. In the third and fourth visits, the related entities were visited to present the research work plan, and physical and/or digital documentation of interest for the research was requested. In the fifth and sixth visits, all the facilities were thoroughly visited, recording all the information about their situation, and identifying the environmental hazards of the AFW. The seventh and eighth visits were carried out to obtain and corroborate information. Finally, a complementary visit was made to the AFW facilities and to the entities to contrast the information obtained in the field with that of the cabinet.

#### **2.3.2 COLLECTION OF DESK INFORMATION**

Data were collected to complete the environmental risk matrices. These data were the following: about the area under study, the fishing activity, and the natural and socioeconomic environments. The shortcomings, modifications and observations to be considered in the environmental hazard and risk analyses were also analyzed.

During all visits, the daily activities of the Pucusana AFW were observed, as well as the fishermen's habits and the way they carry out their work in site.

#### **2.3.3 IDENTIFICATION OF AREAS AND ACTIVITIES AT THE PUCUSANA AFW**

The procedure was as follows:

- Establish the number of areas.
- Recognize the different activities performed in each area.
- Briefly describe the tasks to be performed for each identified activity.
- Check compliance with the checklist, which was complemented by interviewing personnel from Pucusana AFW. This checklist is based on Annex A of the MINAM's Environmental Risk Assessment Guide Matrix, consisting of different requirements to examine, control and identify environmental risks. This checklist is structured and visualized in the existence of an Environmental Adjustment and Management Program (PAMA).

#### **2.3.4 ENVIRONMENTAL RISK ANALYSIS**

This analysis was based on the MINAM Environmental Risk Assessment Guide Matrix (based on the voluntary standard UNE 150008: 2008 - Environmental Risk Assessment

of the Spanish regulatory framework, AENOR) modified to suit the proposed research work and the time of the analysis. The purpose of the Guide is to determine the levels of environmental risks in a geographical area, based on indicators and evaluation criteria. This guide establishes a preliminary evaluation oriented to the study and analysis of an emerging problem or situation followed by the identification of environmental scenarios, which lead to the estimation of environmental risk through a system of matrices for the environments considered.

The methodological sequence is as follows:

1. Identification of Hazard Sources
2. Initiating Event Definition and Scenario Formulation
3. Estimation of the Probability and Severity of Consequences of the Risk Scenarios
4. Environmental Risk Estimation
5. Environmental Risk Assessment and Proposal of Control Measures
6. Environmental Risk Characterization (%)

## IV. RESULTS AND DISCUSSION

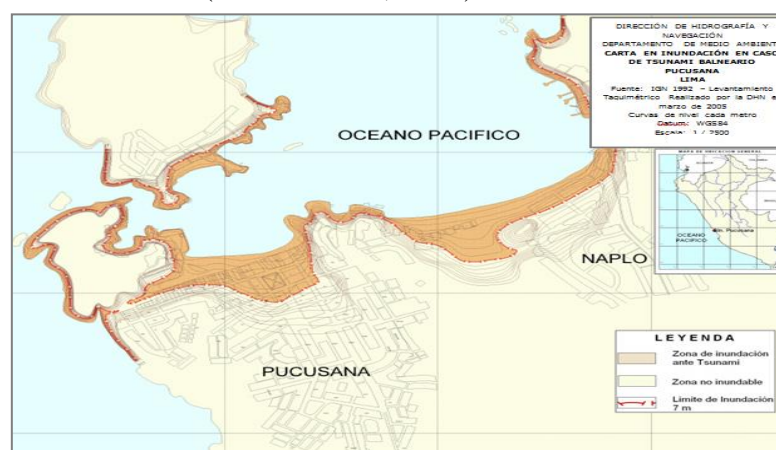
### 4.1 WITH RESPECT TO THE ENVIRONMENTAL ADEQUACY AND MANAGEMENT PROGRAM

In relation to the Checklist, in accordance with current environmental regulations in the production sector, industrial fishing establishments, aquaculture activities and AFW, among others, must have an environmental impact study to ensure the proper functioning of such activities with the least possible impact on the environment, being in the case of AFW that are operational in the presentation of the Environmental Adjustment and Management Program (PAMA).

At the beginning of the investigation, it was noted that the Pucusana AFW did not have a PAMA, so there was no information on environmental management.

### 4.2 REGARDING THE VULNERABILITY OF THE AREA OF INFLUENCE

In Pucusana, there are two natural phenomena that cause major disasters: earthquakes and tsunami inundation. Figure 2 shows the inundation chart of the Pucusana beach resort in the event of a tsunami (HIDRONAV, 2011).



**Figure 2.** Tsunami inundation chart - Pucusana beach area

### 4.3 ENVIRONMENTAL RISK ANALYSIS

#### 4.3.1 IDENTIFICATION OF HAZARD SOURCES

Table 1 shows seven (07) sources of danger identified through the information provided by the entities involved and with the data from the monitoring of seawater quality carried out by DIGESA and IMARPE for scientific and beach health purposes.

**Table 1.** Identification of Hazard Sources in the Pucusana AFW

<b>Danger Sources</b>
<p><b>1.- Current status of offshore infrastructure</b>  Pier 36 years old, exceeding its useful life of 30 years  Deteriorated pier reinforcements and concrete piles</p>
<p><b>2.- Current status of ground infrastructure</b>  Deficient processing area, not appropriate for the volumes landed.  Crowding of people (for washing, trade and disembarkation of species).  The faucet installations have cracks in walls and beams.</p>
<p><b>3.- Inefficient environmental management</b>  A Varadero is improvised in the beach area.  Use of epoxy paint on the beach.  There is no submarine emitter.  Deficient wastewater treatment (sanguaza).  Water from the washing of boats discharged into the sea.</p>
<p><b>4.- Current status of complementary equipment</b>  It does not have an ice producer.  Inadequate conditions of the generator set and electric pumps.  The AFW does not have wash ponds.</p>
<p><b>5.- Limited knowledge of operating techniques and application of standards</b>  Failure to comply with sanitary provisions.  There are no safety procedures or primary processes.  Insufficient training for fishermen.</p>
<p><b>6.- Current status of marine species in Pucusana</b>  Overexploitation of the main hydrobiological resources.  Alteration of the habitat of the species in the area.  Increased presence of sea lions at the dock in search of food.  Increase of jellyfish in the bay due to contamination.  Stranding of crustaceans on Pucusana beach.  Loss of biological diversity (birds, mammals, fish).</p>
<p><b>7.- Inadequate management model for AFW administration and institutions involved.</b>  Excessive delay in authorizing disbursements for infrastructure improvements  Scarce labor supply.  Institutions do not fully comply with regulations.  In high season, the water supply from the public network is insufficient.  Low participation in the care of the environment and hydrobiological resources.</p>

Lack of solid waste management, which generates bad odors and an increase in insects.  
 Increase in the number of vessels.  
 Decrease in the population of fish species generates a decrease in fishing.  
 Decrease in tourism and bathers due to increased beach pollution.

Table 2 shows the list of physical-chemical parameters monitored in the study by IMARPE and DIGESA, grouped for the analysis of environmental risks.

**Table 2.** Water and sediment monitoring of physicochemical parameters in Pucusana Bay, 2005 - 2011

Year	Oils and fats (mg/L)			TSS (mg/L)			Thermotolerant Coliforms (NMP/100ml)			Copper (µg/g)		
	Min.	Prom.	Max.	Min.	Prom.	Max.	Min.	Prom.	Max.	Min.	Prom.	Max.
	2005	1	1	1	18	27	36	---	---	---	---	---
2006	0.2	0.25	0.3	18	42	66	---	---	---	63.33	66.58	69.82
2007	0.1	0.25	0.4	12.4	20.52	28.63	---	---	---	23.52	28.85	34.18
2008	---	0.8	0.8	33.33	39.74	46.15	---	---	---	28.97	32.84	36.71
2009	---	---	---	37.77	93.51	149.25	---	---	---	24.53	25.26	25.98
2010	---	---	---	55.17	69.37	83.57	---	---	---	---	---	---
2011	0.1	8.95	17.8	42.5	142.12	241.73	2	801	1600	17.44	17.44	17.44

Continued...

Year	Cadmium (µg/g)			Zinc (µg/g)			Lead (µg/g)			pH		
	Min.	Prom.	Max.	Min.	Prom.	Max.	Min.	Prom.	Max.	Min.	Prom.	Max.
2005	---	---	---	---	---	---	---	---	---	7.48	7.68	7.87
2006	1	2.99	4.98	94.61	123.07	151.53	6.42	25.66	44.89	7.89	8.02	8.14
2007	0.77	1.43	2.08	20.96	57.23	52.99	5.24	35.33	65.42	---	---	---
2008	0.39	1.47	2.54	50.88	57.23	63.57	2.99	3.74	4.48	7.74	7.86	7.98
2009	0.60	2.70	4.79	79.91	93.24	106.56	0.11	0.57	1.03	7.51	7.61	7.71
2010	---	---	---	---	---	---	---	---	---	7.70	7.75	7.79
2011	0.24	0.24	0.24	90.15	90.15	90.15	1.85	1.85	1.85	6.38	7.27	8.16

SOURCE: IMARPE, 2012; DIGESA, 2012.

#### 4.3.2 DEFINITION OF THE INITIATING EVENT AND FORMULATION OF SCENARIOS

Once the sources of hazards of the Pucusana AFW have been identified, the initiating events or parameters that alter the environment and the risk scenarios they may cause are defined, and depending on the environment they impact, they are classified as natural or socioeconomic, as shown in Tables 3 and 4.

**Table 3.** Definition of the Initiating Event and Formulation of Scenarios in the Natural Setting

Event Initiator/Parameter	Risk Scenario	Causes	Consequences	Source of information
Oils and Fats	Effluents discharged	Cutting and evisceration process	Contamination of the seawater	Yearbook of Environmental Statistics 2013
SST	directly to the sea and soil of the Pucusana Bay	of hydrobiological resources	r and soil of the bay.	Category 2: Coastal marine activities, subcategory 3: Other Activities; Category 4: Conservation of aquatic environments,
Coliforms		Resource laundering process	Loss of quality	
Thermotolerant		hydrobiological	water from the bay.	Coastal Marine Ecosystems, ECA Water (for comparison with results of par- (for comparison with results of par- (for comparison with results of par-
Copper		Embarkation/dise mbarkation process		
Cadmium		Viscera remains		
Zinc		Water for washing utensils		meters taken in water).
Lead		of traders		ECA for Water. Category 1
pH		Remains of fish in a fish hold in		(Summary of Existing Canadian
Sanguaza		the vessel		Environmental Quality Guidelines) (for comparison with parameter results taken in sediments).
		Fish crushing		
		Tap Products		
Solid Waste	Generation of waste	Habits of settlers and workers. AFW's managers, ambulant commerce.	Contamination of the seawater and soil	Yearbook of Environmental Statistics, 2013
	directly thrown into the sea	Lack of distribution garbage cans and solid waste treatment	of the bay.	
		Lack of environmental education		
		Low frequency of solid waste by municipality		



Extract ion indiscriminate of resources hydrobiological al	Populations of hydro- biological resources increasingly more and more scarce	Irresponsible fishing of hydrobiological resources Insensitivity of fishermen for environmental care	Depleti on of resource Unempl oyment Poverty	Project Feasibility Study:  Relocation and construction of the new AFW of Pucusana - Pucusana District - Province and Region-Lima.
Decrease in food sources for birds and marine mammals	Populations of the sea otter, sea lion marine and pelican increasingly scarce for lack of food	Irresponsible fishing of hydrobiological resources Insensitivity of fishermen for environmental care	Loss of diversit y of marine species of the bay	Information about AFW Pucusana from of Sánchez <i>et.al.</i> (2010), Campos (2007), Albañil <i>et al</i> (2005), Austerermühle (2002). Consulting Report IMARPE- Agreement C.P.P.S. on the state of the marine environment.
Constr uction of docks and houses beach	Otter habitat marine in danger	Impact is not taken into account ecosystem ecosystem of the bay	Loss of diversit y of marine species of the bay	Interviews with artisanal and small-scale fishermen and field visits to AFW facilities Pucusana 2012-2013.

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**Table 4.** Definition of the Initiating Event and Formulation of Scenarios in the Socioeconomic Environment

<b>Event Initiator/ Parameter</b>	<b>Risk Scenario</b>	<b>Causes</b>	<b>Consequences</b>	<b>Source of information</b>
Age of the infrastructure of the AFW	Insecurity due to infrastructure deteriorated	Infrastructure of 36 years of age (useful life 30 years) Environmental conditions.	Dock collapse Accidents/situations emergency.	Project Feasibility Study: Relocation and construction of the new AFW of Pucusana - Pucusana District - Province
Current condition of the process area. primary market	Inadequate processing primary	Insufficient space, no sanitary conditions appropriate	Decrease of the product quality Price reduction.	and Region-Lima. Information about AFW Pucusana from Sánchez <i>et.al.</i> (2010), Campos (2007),
Insufficient area parking	Insecure area of parking	Improvisation of a small parking area for private vehicles	Difficult transit Difficult evacuation of people in cases of disasters	Albañil <i>et al</i> (2005), Austerhmühle (2002). Consulting Report IMARPE- Agreement C.P.P.S. on the state of the marine environment. Interviews with fishermen
Current condition of electrical installations cas/sanitary, group generator, electro-pump, product ice	Loss of capacity processing of hydrobiological resource for installations in poor condition	Age of equipment, lack of facilities maintenance, lack of budget for to acquire new equipment	Loss of quality of the product, loss of the dynamics of the AFW by installations in bad condition state	and field visits to the facilities, as well as to the cations of the AFW Pucusana 2012-2013.
Decomposition of organic matter in the bay	Bay odor	AFW's own activity	Uneasiness among neighbors and tourists	Project Feasibility Study: Relocation and construction of the new AFW of Pucusana - Pucusana District - Province
Reduction of maritime area	Marine area of the bay used for	Increase in the amount of fishing vessels.	Loss of the landscape of the bay and space	and Region-Lima. Interviews with fishermen

of the bay	anchoring boats	Lack of space	recreational	and field visits to the facilities, as well as to the
Use of the beach as Varadero	Reduction of the area from Pucusana beach	Lack of space for boat maintenance	Decrease in the number of bathers Beach contamination	cations of the AFW Pucusana 2012-2013.
Reduced quantity of programs of awareness environmental	Institutions involved with insufficient activities that promote go environmental care	Lack of environmental management Lack of environmental awareness	Bay contamination Indifferent population in view of the situation environmental of the bay	
Few offers labor	Increase in unemployment	Fishermen work independently. There is no investment by private companies	Low income of families in Pucusana Increase in poverty.	
Seismic risk	Tsunami risk	Due to seismic movements	Destruction of homes, accidents and fatalities	
Lack of organization AFW management/management	Inadequate management of AFW administration	Lack of training on the AFW management	AFW disorganized Low product quality Inadequate conditions health, safety and health occupational and environmental	Project Feasibility Study: Relocation and construction of the new AFW of Pucusana - Pucusana District - Province and Region-Lima. Interviews with fishermen
Increased resi-solid waste in the	Decrease in tourism	Insufficient garbage cans. Low frequency of	Loss of bay landscape Decrease in attractiveness	and field visits to the facilities, as well as to the cations of the Pucusana AFW 2012-2013.

tourist attractions  
 solid waste by the Municipality  
 Lack of environmental education  
 tourism.  
 Decrease in beach health

### 4.3.3 ESTIMATION OF THE PROBABILITY AND CONSEQUENCES OF RISK SCENARIOS

The probability of occurrence and severity of the consequences of the risk scenarios were estimated, according to environments, as shown in Tables 5 and 6.

**Table 5.** Probability of Occurrence and Severity of Consequences in the Natural Environment

N°	Risk Scenario	Consequences					Probability	
		Quantity	Danger	Extension	Quality of the medium	Valuation		Gravity
1	Effluents discharged directly towards the sea and the bay floor	3	3	4	4	17	4 Severe	5
2	Waste generation directly thrown into the sea	4	1	3	2	9	2 Slight	5
3	Water resources populations increasingly scarce biological resources	3	3	3	3	15	4 Severe	3
4	Sea otter populations, sea lion and pelican each time scarcer due to lack of food	2	3	1	2	11	3 Moderate	3
5	Sea otter habitat endangered	2	3	2	2	12	3 Moderate	3

**Table 6.** Probability of Occurrence and Severity of Consequences in the Socioeconomic Environment

N°	Risk Scenario	Consequences					Valuation	Gravitation	Probability
		Quantity	Danger	Extension	Equity and Productive Capital				
6	Infrastructure insecurity	3	3	2	3	14	3	3	
	deteriorated.						Mode rate		
7	Inadequate processing area	2	3	2	3	13	3	3	
	primary.						Mode rate		
8	Unsafe parking area.	2	3	2	3	13	3	3	
							Mode rate		
9	Loss of processing capacity of	3	2	2	3	14	3	3	
	hydrobiological resources due to installations in poor condition.						Mode rate		
10	Bad odor from the bay.	2	1	2	1	7	1 Not Relevant	4	
11	Marine space of the bay	3	2	2	3	12	3	4	
	used for anchoring boats.						Mode rate		
12	Reduction of beach area.	2	3	2	3	13	3	4	
							Mode rate		
13	Institutions involved	2	2	3	3	12	3	3	
	perform insufficient activities that promote environmental care.						Mode rate		
14	Increase in unemployment.	3	2	3	2	12	3	3	
							Mode rate		
15	Tsunami risk.	3	3	4	3	17	4	3	
							Severe		
16	Inadequate management of the	2	3	3	2	13	3	3	
	administration of the AFW.						Mode rate		
17	Decrease in tourism.	3	3	2	3	14	3	4	
							Mode rate		

#### 4.3.4 ENVIRONMENTAL RISK ASSESSMENT

Environmental risk was determined for the natural and socioeconomic environments, as shown in Table 7.

**Table 7.** Environmental Risk Estimation

<b>Analysis of the Natural Environment</b>					
Probability of occurrence	Severity of consequences				
	1	2	3	4	5
1					
2					
3			E4, E5		E3
4					
5		E2			E1
<b>Analysis of the Socioeconomic Environment</b>					
Probability of occurrence	Severity of consequences				
	1	2	3	4	5
1					
2					
3			E6, E7, E8, E9 E13, E14, E16		E15
4	E10		E11, E12, E17		
5					

#### 4.3.5 ANALYSIS AND INTERPRETATION OF RESULTS

The results obtained according to the environment, with its risk scenarios and the initiating event, are presented below.

##### 4.3.5.1 Natural Environment

###### a) Effluents discharged directly into the sea and soil of Pucusana Bay: a.1 Oils and greases.

The range of values for oils and fats fluctuated between 0.1 mg/L to 17.8 mg/L, with 17.8 mg/L was the maximum value observed in 2011; this value exceeds the ECA limits for the oils and fats parameter, because the value for Category 2, in its subcategories C1, C2 and C4, is 1 mg/L and for subcategory C3, it is 2 mg/L; this means that the seawater near the Pucusana AFW is not suitable for coastal marine activities of extraction and cultivation of bivalve mollusks, nor for the extraction and cultivation of other hydrobiological species.

During the period 2005-2011, the concentration of oils and fats has been increasing and has presented concentrations that exceed the ECA. The main sources of fats and oils identified at the landing site are bilge water, water from the bilge, the washings and remains of the species landed.

###### a.2 Total Suspended Solids

The range of TSS values fluctuated between 42.5 mg/L to 241.73 mg/L. The maximum value observed in 2011 was 241.73 mg/L, which exceeds the ECA limits for the TSS parameter,

because for Category 2, in its subcategories C1, C2 and C3 it is 80, 60 and 70 mg/L respectively and for subcategory C4, no value is recorded.

This also means that the seawater near the Pucusana AFW is not suitable for the marine-coastal activities of extraction and cultivation of bivalve mollusks, nor for the extraction and cultivation of other hydrobiological species. The main sources identified as TSS contributors at the landing site are bilge water; sewage; washing and remains of landed species.

### **a.3 Thermotolerant Coliforms**

During the water quality monitoring of Pucusana beach conducted by DIGESA in 2011, it was observed that in 12 weeks its rating was unhealthy, reaching values above 1000 NMP/100 ml. In 2012, a similar behavior was observed; in 11 weeks its rating was Unhealthy.

Seawater exceeds the ECA limits for the thermotolerant coliform parameter. The limits for Category 2, in its subcategories C1 and C2 are  $\leq 88$  NMP/100 ml and  $\leq 30$  NMP/100ml respectively; for subcategory C3 it is 1000 NMP/100 ml; likewise for category C4 the minimum value of 200 NMP/100mL is exceeded. This means that the seawater near the Pucusana AFW is not suitable for coastal marine activities for the extraction and cultivation of bivalve mollusks, nor for the extraction and cultivation of other hydrobiological species. The main identified sources of coliforms come mainly from the excrement of seabirds such as pelicans, seagulls, etc., as well as from the discharge of wastewater from fish washing and neighboring housing complexes.

### **a.4 Copper**

The dependent variable is the concentration of total copper in benthic organisms expressed in dry weight ( $\mu\text{g/g}$  equivalent to mg/kg). In the period 2005-2011, the copper concentration has decreased being the minimum value 17.44 mg/kg in 2011, which is a value above what is allowed according to the ECA for Category 2; in subcategories C2 and C3 it is 0.05 mg/L, in subcategory C1 it is 0.0031 mg/L and in subcategory C4 the minimum established is 0.2 mg/L.

The main source of copper in the AFW possibly comes from copper epoxy paint, which is used to paint the boat's hull to prevent aquatic organisms such as mollusks and algae from adhering to the base of the boat. The painting is done at the natural dry dock on Pucusana beach. The copper contaminant found in the paint on the boats comes into permanent contact with the seawater. Paint residue from the dry dock also reaches the sea through the waves, deposited on the seafloor.

### **a.5 Cadmium**

The range of cadmium values in the 2005-2011 period is fluctuating, with the minimum value being 0.24 mg/kg in 2011; this value is above the permitted value according to the ECA for Category 2, in subcategories C1, C2 and C4 it is 0.01 mg/L, and for subcategory C3, no value is recorded.

In the Pucusana AFW, the sources of cadmium possibly come from the nature of the bay itself, from rocks and marine sediment; there are no natural phenomena such as volcanic eruptions or forest fires that could contribute cadmium. The main possible sources of

cadmium in Pucusana Bay are domestic waste, construction debris, and rocks that are dislodged from their place of origin.

#### **a.6 Zinc**

The range of zinc values fluctuated in the period 2005-2011, with a value of 90.15 mg/L in 2011. This value is above what is allowed according to the ECA for Category 2, in subcategories C1 and C2 it is 0.081 mg/L, for subcategory C3, it is 0.12 mg/L and for subcategory C4 it is 1.0 mg/L.

At the landing site, the sources of zinc possibly come from discarded batteries, which are in daily use by fishermen (source of energy for the boat's light signals, for their appliances, GPS, flashlights, and others).

#### **a.7 Lead**

The range of lead values in the period 2005-2011 indicates that the concentration of lead has been decreasing over time, with the minimum value being 1.85 mg/kg in 2011. This value is above what is allowed according to the ECA for Category 2, in subcategories C1 and C2 it is 0.0081 mg/L, in subcategory C3 it is 0.03 mg/L and in subcategory C4 it is 0.0025 mg/L. The sources of lead possibly come from the tap, gasoline 84 is the fuel most used by boats with outboard engines and has a high percentage of lead. Over time the fuel has possibly been deposited in seawater and seabed due to small spills, thus increasing its concentration.

#### **a.8 pH**

The maximum value found was 7.27 in 2011, which does not exceed the ECA limits for the pH parameter. This maximum value is within what is allowed according to the ECA for Category 2, in subcategory C1 with a value of 7-8.5; in subcategories C2 and C3, the value is 6.8-8.5, and for subcategory C4, the value is 6.0-9.0. This means that the seawater near the Pucusana AFW complies with the ECA.

#### **a.9 Sanguaza**

In 2011, FONDEPES determined that in one ton of volume landed in the Pucusana AFW there is a 10% loss in the entire process. Assuming that the loss is made up of sand and solids and taking the figure of 10,195 tons landed at Pucusana in 2010, we can deduce that approximately 1,019 tons of sand and solids were produced at the landfill in that year.

Sanguine and solid remains on the boats (from crushing the fish caught, washing the holds and generating bilge water) are discarded or dumped into the sea near the landing dock, increasing the concentration of organic matter and negatively altering the sanitary quality of the beach.

#### **b) Generation of waste directly thrown into the sea: solid wastes**

The environmental pollution problem in Pucusana Bay is due to a lack of awareness of the environment, a lack of environmental awareness among fishermen, a lack of management by the authorities, deficiencies in waste disposal, and a lack of participation by the entities involved to better manage the generation of waste and residues.



**c) Increasingly scarce stocks of hydrobiological resources: indiscriminate extraction of marine resources**

There is a decrease in the number of species caught near the AFW, as perceived by the fishermen themselves; these species are: mackerel, silverside, and squid. Artisanal fishermen do not have a fishing limit and seek to catch as many species as possible without respecting the storage capacity limit and reducing the mesh size of the net, which ensures that they catch more species. There is no sustainable management of marine resources, nor are there measures to preserve or seek to prolong the permanence of schools of fish.

**d) Sea otter, sea lion and pelican populations increasingly scarce due to lack of food: declining food sources for birds and marine mammals**

Indiscriminate fishing of marine resources contributes to the reduction of food sources for mammals and birds that live near Pucusana Bay, such as sea otters, sea lions, and guano birds, because artisanal fishermen, upon learning of the existence of a school of fish near the bay, begin to compete to extract as much of the localized marine resource as possible.

**e) Endangered sea otter habitat: Construction of piers and beach houses**

A large number of houses and/or apartments under construction were observed around the bay, reducing the otter's habitat. Also, testimony was obtained from construction workers in the area who state that there are more construction projects for exclusive villas and apartments in the vicinity of the beach. On the other hand, the Pucusana AFW remodeling and expansion project is still on hold even though it has been proven to be unfeasible.

#### **4.3.5.2 Socioeconomic Environment**

**a) Insecurity due to deteriorated infrastructure: age of the AFW**

The current infrastructure has been built many years ago, and over time it has been extended, but it is no longer possible to expand it; its internal structure and the base where it is supported are deteriorated, which increases the insecurity of users and economic activity.

**b) Inadequate primary processing area: Current condition of the processing area**

At the time of the analysis of this study (2012), the primary processing area had not yet implemented the Good Processing Practices Manual, i.e., it was working in an unhealthy environment.

**c) Insecure parking area for vehicles: insufficient parking area**

The parking area inside the AFW cannot accommodate all the vehicles that park regularly: trucks and isothermal chambers that collect the hydrobiological product to be marketed, private vehicles of fishing companies, private cars of the owners of the neighboring houses and of the personnel that work in the area; this situation causes a great deal of traffic congestion and makes the area unsafe.

**d) Loss of processing capacity of hydrobiological resources due to facilities in poor condition: current condition of electrical and sanitary installations.**

The electrical and sanitary installations were found to be in poor condition and the restrooms are inadequate and unsanitary. The AFW does not have an ice maker. The AFW acquired a new generator in November 2012; however, the environment where it was located has humidity and small puddles of water that could cause a short circuit or fire.

**e) Bay odor: organic matter decomposition**

The foul odor generated by the decomposition of organic matter and the remains of hydrobiological species landed in the AFW causes discomfort among the neighbors in the area. In addition, the lack of maintenance of the drainage networks to carry the effluents generated in the AFW increases the bad odor in the environment.

**f) Marine space in the bay used for anchoring vessels: reduction of the marine space in the bay.**

There are a large number of artisanal fishing vessels occupying a large area of the bay, many of which are overcrowded, making it difficult to find a suitable place to anchor them and increasing the risk of collision between them.

**g) Reduction of the recreational area of Pucusana beach: use of the beach as a dry dock**

Artisanal fishing boats require maintenance, so artisanal fishermen beach them on Pucusana beach and carry out activities that have negative impacts on the bay, such as the use of toxic paints, generation of various types of waste, visual pollution, etc., which alter the environment and reduce the recreational area of the beach.

**h) The institutions involved carry out insufficient activities to promote environmental care: reduced number of environmental awareness programs.**

The entities involved have little participation in the care and conservation of Pucusana Bay's environment, although they are very important entities that can contribute to the environmental awareness of the population.

**i) Increasing unemployment: few job offers**

The most common jobs are artisanal fisherman, fish trader, motorcycle cab driver, or restaurant worker. Working as an artisanal fisherman is a very competitive occupation due to the scarcity of marine resources.

**j) Tsunami risk: seismic risk**

There are no evacuation routes in the AFW that are posted and/or published in a visible place, nor are there any safety zones in case of an earthquake and/or tsunami, even though Pucusana is considered a highly seismic zone by INDECI.

**k) Inadequate management of the AFW administration: lack of organization and management**

The management model of the current administration is basically concerned with the operation and production of the AFW and with attending to the problems and needs of the fishermen; however, there is little concern for the safety and health of AFW users and personnel, nor for the contamination of the bay. Likewise, each new group of fishermen elected to manage the AFW takes control and does not continue the work of the previous administration.

**l) Decrease in tourism: increase in solid waste at tourist attractions.**

The Boquerón is a very attractive geological formation for visitors to the bay; however, there is a certain amount of solid waste deposited in its structure, such as plastic wrappers, plastic bottles and glass bottles, which are thrown away by the residents of Pucusana and by foreigners; this bad practice takes away the beauty and attractiveness of the Boquerón.

#### **4.3.6 ENVIRONMENTAL RISK ASSESSMENT AND PROPOSED CONTROL MEASURES**

Table 8. presents the environmental risk assessment and control measure for each risk scenario for the natural and socioeconomic environments.

**Table 8.** Environmental Risk Assessment and Control Measures (P: Likelihood; G: Severity)

Natural Environment						
N°	Event Initiator/ Parameter	Risk Scenario	P	G	Environmental Risk	Control Measures
	Oils and Fats					- Prohibit and fine the discharge into the sea of bilge water, bilge water, species wash water and boat wash water.
	SST					- Decrease the amount of wastewater and solid waste generated in the process of landing products that are finally dumped into the sea. - Fining people who carry out these activities.
1	Thermotolerant Coliforms	Effluents discharged directly into the sea and soil of the Pucusana Bay.	4	5	80 Significant	- Review the sewage system of the AFW and neighboring housing complexes to determine the destination of their wastewater and thus rule out discharge into the sea. - The administration of the AFW, which oversees the wharf; the Captaincy, which administers Galapagos Island; and the Municipality, which has jurisdiction over all the houses bordering the bay, should work together with SEDAPAL to demand that the projects that are still pending be executed and that the direct discharge of wastewater into the sea be eliminated or mitigated.
	Copper					- The AFW administration, together with the Captaincy, should look for another place to dry dock the boats, in addition to prohibiting and fining the maintenance and painting of boats on Pucusana beach. - The paints used on boats should be controlled and/or supervised since many of them are pollutants to the environment.

## Natural Environment

N°	Event Initiator/ Parameter	Risk Scenario	P	G	Environmental Risk	Control Measures	
1	Cadmium	Effluents discharged directly into the sea and soil of the Pucusana Bay.	4	5	80	Significant	<ul style="list-style-type: none"> <li>- The Municipality of Pucusana and the Captaincy have jurisdiction on land and at sea, respectively, and should follow up on the construction of houses in Pucusana Bay to avoid bad practices that alter the environment, such as dumping cement debris into the sea.</li> <li>- Fining people who throw solid waste into the sea, as it may contain cadmium in its composition.</li> <li>- Conduct a riparian morphological study of the area to determine if there are natural sources of cadmium.</li> </ul>
	Zinc						<ul style="list-style-type: none"> <li>- Implement a non-metallic container where used batteries and cells are stored. There are suppliers that accept used batteries for industrial recycling.</li> </ul>
	Lead						<ul style="list-style-type: none"> <li>- To monitor and control the amount of lead used in the fuel of the vessels and to know its final disposal.</li> <li>- Implement an emergency plan at the tap to prevent and/or avoid fuel spills.</li> <li>- Dispose of batteries containing lead in containers.</li> </ul>
	pH						
	Sanguaza						<ul style="list-style-type: none"> <li>- Prohibit and fine the dumping of water into the sea.</li> <li>- Implement a device for pumping the sewage from the hold of each vessel to a sump or treatment plant.</li> </ul>

<b>Natural Environment</b>							
N°	Event Initiator/ Parameter	Risk Scenario	P	G	% Environmental Risk	Control Measures	
2	Solid Waste	Generation of waste directly thrown into the sea.	5	2	40	Moderate	<ul style="list-style-type: none"> <li>- Build collection points for these wastes, built of brick and cement or determine a fenced space, for later disposal and/or recycling.</li> </ul>
3	Indiscriminate extraction of marine resources	Increasingly scarce stocks of hydrobiological resources	3	4	48	Moderate	<ul style="list-style-type: none"> <li>- The AFW administration should exercise greater control over the species landed by the AFW, supervising minimum sizes, minimum mesh size and the type of fishing allowed.</li> <li>- Involved institutions such as PRODUCE and IMARPE should conduct research studies on the characterization of Pucusana Bay and its surroundings, to learn about the behavior of the schools of fish and other species in the area, in order to have more knowledge about the amount that should be caught.</li> <li>- Compliance with the hold capacity limit for each vessel must also be monitored.</li> </ul>
4	Decrease in food sources for birds and marine mammals	Sea otter, sea lion and pelican populations scarcer due to lack of food	3	3	36	Moderate	<ul style="list-style-type: none"> <li>- In Peru, the sea otter is protected because it is an endangered species.</li> <li>- Certain areas of Pucusana Bay should be considered as protected areas to prevent the hunting and/or killing of the sea otter in order to preserve it.</li> <li>- Responsible fishing.</li> </ul>
5	Construction of piers and beach houses	Endangered sea otter habitat	3	3	36	Moderate	<ul style="list-style-type: none"> <li>- PRODUCE should work hand in hand with those NGOs that protect marine mammals in the area, which have research, information and knowledge of the behavior of these animals; this would allow them to have more criteria for making decisions regarding the AFW (modifications, reforms, fishing, pollution, etc.). In addition, these NGOs should train fishermen to raise awareness of the current problem.</li> </ul>

Continued

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## Socioeconomic Environment

N°	Event Initiator/ Parameter	Risk Scenario	P	G	Environmental Risk	Control Measures	
6	Age of AFW infrastructure	Insecurity due to deteriorated infrastructure	3	3	36	Moderate	<ul style="list-style-type: none"> <li>- Relocate the Pucusana AFW to a place where it does not affect the ecosystem.</li> <li>- It is advisable not to continue remodeling, expanding and/or restructuring the AFW, since, if modifications are made, the infrastructure may collapse.</li> </ul>
7	Current condition of the processing area (washing, evisceration and filleting).	Inadequate primary processing area	3	3	36	Moderate	<ul style="list-style-type: none"> <li>- Improve the situation of the area (modification of the material of the tables and improvement of accessories and utensils for the processing of hydrobiological resources), in addition to implementing adequate clothing for the workers and constant cleaning of the place.</li> <li>- The entire deteriorated platform that makes up the parking lot must be improved and signposted, respecting the continuity of the road that leads to Las Ninfas beach.</li> </ul>
8	Insufficient parking area	Unsafe parking area	3	3	36	Moderate	<ul style="list-style-type: none"> <li>- Relocation of the AFW.</li> <li>- Relocation of the vehicular parking lot.</li> <li>- Establish a limit on the number of cars that can be parked.</li> </ul>
9	Current condition of electrical and sanitary installations, generator, electric pumps and ice maker.	Loss of processing capacity of hydrobiological resources due to facilities in poor condition	3	3	36	Moderate	<ul style="list-style-type: none"> <li>- Repair and renovate all electrical installations, keeping them isolated from contact with water.</li> <li>- AFW management should improve the cleanliness of the restrooms and implement them more.</li> <li>- Condition the environment exclusively for the generator set, eliminating any trace of water.</li> <li>- To isolate or cover the electric pumps.</li> <li>- Implement an ice producer.</li> </ul>

<b>Socioeconomic Environment</b>							
N°	Event Initiator/ Parameter	Risk Scenario	P	G	Environmental Risk	Control Measures	
10	Decomposition of organic matter in the bay	Bay odor	4	1	16	Slight	<ul style="list-style-type: none"> <li>- Wastewater and sewage treatment.</li> <li>- Improvements in the handling and temporary storage of captured hydrobiological resources.</li> </ul>
11	Reduction of maritime space in the Bay	Marine space in the bay used for anchoring vessels	4	3	48	Moderate	<ul style="list-style-type: none"> <li>- The harbor master's office should restrict the entry of more permanent vessels into the bay.</li> <li>- Establish specific anchorage zones for boats.</li> <li>- In high fishing seasons, establish a limit on the number of boats that can enter the Pucusana AFW.</li> </ul>
12	Use of the beach as a dry dock	Reduction of the Pucusana beach area	4	3	48	Moderate	<ul style="list-style-type: none"> <li>- Prohibit the use of the beach as a dry dock or define the beach area to be used as a dry dock with rules and conditions that promote environmentally friendly practices.</li> </ul>
13	Reduced number of environmental awareness programs	The institutions involved carry out insufficient activities to promote environmental care.	3	3	36	Moderate	<ul style="list-style-type: none"> <li>- The AFW Administration, the Municipality and PRODUCE should work together to solve environmental problems in Pucusana. They should also strengthen communication with the fishermen about environmental care and conservation by means of notices, campaigns, and changes in processes or activities within the dock that minimize marine pollution.</li> <li>- The Municipality should promote environmental education in schools, through cleanup campaigns, talks, the installation of more garbage cans, informative notices, regulations, etc. to eliminate and/or prevent contamination of the bay.</li> </ul>
Continued...							
<b>Socioeconomic Environment</b>							



N°	Event Initiator/ Parameter	Risk Scenario	P	G	Environmental Risk	Control Measures	
14	Few job offers	Increase in unemployment	3	3	36	Moderate	<ul style="list-style-type: none"> <li>- The municipality should contribute to the growth of the district through tourism, promoting the attractions of Pucusana Bay, taking advantage of the flora and fauna, and working together with artisanal fishermen.</li> <li>- It is necessary to mention that currently there are tours around the boardwalk, however it should be promoted even more, campaigns and advertising to sell more tourism in Pucusana.</li> </ul>
15	Seismic risk	Tsunami risk	4	3	36	Moderate	<ul style="list-style-type: none"> <li>- The Municipality and the AFW Administration, with the support of INDECI, should signpost the entire beach area and the wharf as a preventive measure in the event of a natural phenomenon, in addition to conducting information campaigns on safety zones and earthquake and tsunami drills.</li> </ul>
16	Lack of organization and management of the AFW	Inadequate management of AFW administration	3	3	36	Moderate	<ul style="list-style-type: none"> <li>- The AFW administration should encourage and propose research projects that will help to learn more about the current situation of its infrastructure and natural environment.</li> <li>- It is recommended that FONDEPES and PRODUCE work together to advise the AFW on production processes and environmental management of natural resources.</li> </ul>
17	Increase in solid waste at tourist attractions	Decrease in tourism	4	3	48	Moderate	<ul style="list-style-type: none"> <li>- The municipality should carry out a cleanup campaign in Boquerón, cleanup and awareness programs, segregation, handling and management of solid waste.</li> </ul>

#### **4.3.7 ENVIRONMENTAL RISK CHARACTERIZATION**

The environmental assessment conducted at the Pucusana AFW characterized the following environmental risk:

- Natural Environment                      48.00 %
- Socioeconomic Environment            37.33 %

Likewise, the Pucusana AFW has an environmental risk of 42.67%, a risk categorized as Moderate, which merits immediate mitigation measures, since its population, environment and socioeconomic environment are severely affected.

As of 2018, the environmental problems continued, and they did not have the respective Environmental Certificate (PRODUCE, 2018).

## V. CONCLUSIONS

1. The Pucusana AFW has an average environmental risk of 42.67%, which is classified as Moderate and warrants taking control measures to reduce the risk.
2. The level of risk in the natural environment is 48% and in the socioeconomic environment 37.33%. The natural environment has a higher level of risk due to the presence of contaminating substances.
3. The environmental risks have a physical-chemical cause, mainly of anthropogenic origin, which alter the quality of the seawater. The parameters oils and fats, TSS and thermotolerant coliforms exceed the ECA limits, which means that the water is not suitable for coastal marine activities such as extraction and cultivation of bivalve mollusks. The pH parameter is within the ECA and the parameters copper, cadmium, zinc and lead have values that are higher than the Environmental Quality Standards (EQS) for water.

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### **Conflicts of interest**

The undersigned authors declare that they have no potential personal or financial conflicts of interest with other persons or organizations that could unduly influence this manuscript.

### **Authors' contributions**

Preparation and execution: MDG, DCO, RMH and RMC; Methodology development: MDG, DCO and RMH; Conception and design: MDG and RMC; Article editing: MDG and RMC; Study supervision: RMC.

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