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Perception on the Risk of the Sonora River Pollution

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Abstract: This study applies the "psychometric paradigm" of risk perception to the heavy mineral spill in the Sonora River (Mexico). A total of 241 inhabitants of the polluted area with a mean age of 46.3 years participated in the study, completing an interview questionnaire at the onset of the disaster. The results allow us to establish a profile of the 18 characteristics comprising the model and a multiple regression analysis shows that some characteristics of the dimensions of dread risk and unknown risk explain a percentage of the magnitude of the perceived risk. In addition, the behaviors recommended by the authorities were classified by the participants according to their estimated usefulness. Significant differences were observed. Avoiding contact with the water was considered the most effective, followed by recommendations on the use of the water, with actions related to the environment and how to avoid pollution being considered the least effective. In sum, the strategy deployed allows us to observe how the victims perceive the disaster and organize the behaviors proposed by the authorities.

Keywords: risk perception; psychometric paradigm; environmental risk behaviors emergency; aquifer contamination; illness

1. Introduction

This research concerns a catastrophe that occurred in Mexico on 6 August 2014, which the Mexican Federal Government (SEMARNAT) called the "worst environmental disaster in the country's mining industry in modern times" [1]. The accident occurred at Grupo México's Buenavista del Cobre copper mine, and was caused by a spill of 40,000 m^3 of acidulated copper sulfate into Arroyo de las Tinajas, a stream in Cananea (Sonora state), which polluted a stretch of nearly 300 km in three river basins: Tinajas, Bacanuchi and Sonora. The disaster affected seven towns, impacting on wells and the water supply as described in Reforma (27 August 2014), cited by [2]. The work by Alfie Cohen [2] reports that the accident was caused by the absence of a valve in the leachate pools as well as the lack of other infrastructures. The damage had a major impact on economic activity in the area, quality of life and inhabitants' health. The situation was not new: five years earlier, warnings had already been made about these risks and workers had drawn attention to other problems in the mining facility. This catastrophe could well be included in what Turner labelled "the disaster incubation period" [3], because warnings had been given of what could happen but no action had been taken.

A disaster of this nature, with a major impact in the media and the intervention of numerous government agencies, unfortunately provides an opportunity to investigate risk perception in a population exposed to a catastrophe of this magnitude. In addition, it is possible to assess how the population perceived the recommendations issued by the authorities in order to prevent possible diseases resulting from the disaster. The aim of this study is not only to analyze a particular incident, but also to help improve the management of this type of disaster, and the decisions taken in this sort of situation.

There are a number of risk perception studies regarding crises or disasters related to water pollution. In Mexico, Arellano, Camarena, von Glascoe and Daesslé [4] identify dimensions related to medium- and long-term health risk, caused by pollution from agriculture and mining at the mouth of the Hardy and Colorado rivers. Among their findings, we can highlight how risk perception increases in the presence of acute pollution-related diseases, as well as variables related to participants' educational level and family income.

Regarding the geographical area related to this study, we find the work conducted by Robles-Morua, Halvorsen, and Mayer [5], which focuses on how the inhabitants of this basin perceive diseases derived from the domestic water supply, their causes and the proposed solutions. These authors base their decision to conduct the study in this location on the inhabitants' exposure to illnesses resulting from the highly polluted water supply and the levels of poverty in the area, as well as the public authorities' lack of interest of in the matter.

One of the most important findings of the work by Robles-Morua et al. [5] is that many of those interviewed were unaware of the problem caused by the water supply: 33% admitted that they did not consider it a health threat. However, the authors find differences in risk perception according to the income level of the respondents, noting that the wealthiest perceive the greatest risk of disease due to water pollution. Moreover, both the general public and members of local government perceived less risk of disease due to water pollution than professionals. The study shows that local politicians attributed the diseases to the hygiene practices of the affected population and not to the water supply. Comparable findings have been reported in similar populations in Nogales [6], an area near the Sonora River basin. However, studies conducted in more economically developed areas, but in the same geographical region—Hermosillo [7] and Arizona [6]—find that inhabitants consider water pollution as a high personal risk.

All the previously mentioned studies use either a qualitative or a quantitative methodology, in an attempt to evaluate risk perception with specific reference to areas located near polluted rivers. As has been observed, these works are multidisciplinary in nature, depending on their analytical perspective. Studies on risk perception of disasters have been conducted from the perspective of different disciplines such as psychology, sociology or cultural anthropology, among others [8], and depending on the approach, the research has generated numerous concepts and theories that have hindered the emergence of a common integrated approach [9]. This is reflected in the complex definition of risk perception proposed by [10], highlighting a multidimensional character which combines beliefs, attitudes, judgments, feelings and values. While this has been an obstacle to the analysis of the complexity of risk perception, these approaches have revealed particularities of each individual risk and the perspective of each field.

Much attention has been given to the so-called "psychometric paradigm" [11–14]. This approach shows that people perceive risks mapped onto two orthogonal dimensions—dread and unknown—and these, in turn, are related to the magnitude of the perceived damage [15,16]. The research on risk perception using this model has studied the conjoint perception of heterogeneous risk [17]. However, a number of other studies focus on risks belonging to a single category, such as, for example, food-related risk [18]. The main purpose of the model is to show a map of risks for a particular context or population, as has frequently been suggested [19]. To sum up, we can say that this approach has a clear cognitive orientation resulting from the tradition of bounded rationality and that risk perception is a direct function of the properties attributed to the risks; i.e., the focus is placed on the risk and not on the individuals who perceive it [20,21].

In this approach, there are few monographic studies examining risk perception on a single event: however, there are noteworthy exceptions such as those on severe acute respiratory syndrome (SARS) [22] or on the influenza A virus (H1N1) [23].

From the methodological point of view, this model represents a scaling procedure to obtain quantitative measures of different qualitative characteristics of the perceived risks. The number of characteristics used in the research has varied over time, and according to the objectives of the research. Initially, 18 items were used [24,25], which were subsequently reduced to nine [8]. One of the reasons for this reduction is the number of risks evaluated in each study. In any event, however many characteristics are used, the aim is to obtain a profile of each risk based on the dimensions of dread and unknown.

The relationship between risk perception and behavior does not appear to have been a central objective of these studies; rather, they focus on attempting to explain why individuals perceive risk [26]. However, this core issue of behavior should not be disregarded in favor of risk management. Identifying the most effective behaviors in a situation of danger, how individuals react to the instructions provided by the authorities, or how they assess these instructions are central aspects to improve the ways in which populations affected by disasters tackle the ensuing catastrophes.

The behaviors that individuals exhibit in a situation of risk are affected by how the risk is perceived and their beliefs regarding this risk. Thus, this perception can modify their behavior towards the risk itself [27,28]. In this line, it is worth highlighting the studies conducted in the field of health risks that relate the perceived risk of infectious disease to strategies to avoid contagion [23,29–32].

The opportunity to apply the "psychometric paradigm" to a health and environmental risk as a result of a catastrophe such as the pollution of a river basin is of great interest because there are very few studies on risk perception associated with a single event of these characteristics. In addition, this model allows us to establish a profile of the qualitative characteristics of a specific risk following data collection from a large number of participants in a short period of time, and to identify their relationship with the magnitude of the perceived risk. Therefore, the specific objectives of this work can be formulated as follows:

Our first objective is to evaluate the qualitative characteristics proposed by the "psychometric paradigm", based on responses from a sample of the population affected by the disaster in the river basins in the state of Sonora (Tinajas, Bacanuchi and Sonora), as a result of the copper sulfate spill. Our second objective is to determine to what extent these evaluations predict the magnitude of the perceived risk. Finally, we focus on the affected populations' perception of the authorities' recommendations on how to behave in response to the situation.

2. Materials and Methods

2.1. Participants

This study was conducted with a sample of 241 participants, all of whom gave their informed consent. All participants were residents of the eight villages whose municipal borders are marked by the banks of the Sonora River. All participants were interviewed in their street of residence; interviewers were assigned quotas based on age and gender. The mean age of participants was 46.31 (SD = 16.64) years. A total of 56% were women. Regarding educational level, distribution was the following: 31.2% of participants had completed primary education, 51.1% secondary education or high school, and 17.7% held a university degree.

2.2. Questionnaire and Procedure

The questionnaire included a Spanish adaptation of the risk perception scale [33], comprising 18 items, as the study referred to a single event. A 4-point scale was used rather than a 7-point one, due to the high number of participants with a low educational level (see Appendix A). In addition, an item measuring the magnitude of the perceived risk was included ("Likelihood of disease related to pollution of the Sonora River"). This was also measured on a 4-point scale, where 1 indicated no likelihood and 4 represented a great likelihood.

Furthermore, another section was devoted to the recommendations given by the authorities to prevent disease, consisting of 11 items, assessed on a scale of 1 to 4, where 1 was not useful and 4 very useful. Finally, different sociodemographic questions relating to participants' gender, age and level of education were included.

The questionnaire was administered in the area of the banks of the Sonora River, in the towns of Ures, Mazocaui, La Aurora, Huépac, San Felipe de Jesus, Baviácora, Aconchi and Arizpe. Fieldwork was conducted by 10 previously trained interviewers, who were graduate students at the University of Sonora. Data was collected in the first weeks following the Sonora River toxic spill.

2.3. Data Analysis

In order to determine to what extent the characteristics of risk perception predict the magnitude of the perceived risk, we conducted a stepwise multiple regression analysis. Furthermore, in order to evaluate how behaviors are grouped according to the perceived degree of usefulness, we conducted a principal axis factor analysis with varimax rotation and a repeated measures variance analysis to determine whether there were differnces in the degree of usefulness of the behaviors. Finally, we carried out a variance analysis and a *t*-student's test to study the effect of the sociodemographic variables.

3. Results

First, we analyzed the scores for the 18 risk characteristics evaluated, the results of which are shown in Table 1. In this table, the characteristics are grouped according to the dimensions of unknown and dread set out in the works on the "psychometric paradigm". The variable with the highest mean score was the estimate of people exposed to risk—"People exposed"—($M = 3.63$; $SD = 0.73$). Within the dread dimension, the characteristics with the highest average mean scores were the perception that this risk is not easily reduced ($M = 3.26$; $SD = 0.92$); that it will affect future generations ($M = 3.24$; $SD = 0.92$), and that the allocation of resources is equitable ($M = 3.11$; $SD = 0.98$).

Table 1. Univariate statistics of the 18 features from the "psychometric paradigm" model.

Variable	*N*	Mean	Standard Deviation
DREAD			
Involuntary (Item 1)	238	2.98	1.09
Uncontrollable (Item 5)	238	2.89	1.00
Catastrophic potential (Item 7)	232	2.04	0.83
Fatal Consequences (Item 8)	236	2.69	0.96
Dread (Item 9)	239	2.97	1.02
Preventive Control (Item 10)	238	2.78	1.21
Risk to Future Generations (Item 12)	237	3.24	0.92
Immediate Effect (Item 13)	237	2.69	1.02
Equitable (Item 14)	238	3.11	0.98
Global Catastrophic Item 15)	237	2.73	0.99
Risk Increasing (Item 17)	238	2.53	1.05
Not easily reduced (Item 18)	238	3.26	0.92
UNKNOWN			
Effect Delayed (Item 2)	237	2.86	1.01
Unknown to Those Exposed (Item 3)	239	2.77	1.01
Unknown to Science (Item 4)	237	1.74	0.85
New Risk (Item 6)	238	2.93	1.19
Not observable (Item 16)	237	2.65	1.03
People exposed (Item 11)	238	3.63	0.73

Note. The italicized terms correspond to the characteristics of Slovic, Fischhoff and Lichtenstein [16].

The analysis of the extent to which the variables of gender and level of education affected the evaluation of the characteristics showed that in the case of gender, there were only differences in two of the eighteen characteristics—catastrophic potential and the number of people exposed—in both cases women scored higher than men. Similar results are found when comparing the evaluations of characteristics according to educational level. In this case, the ANOVAs only showed significant differences in the item referring to the consequences of the catastrophe for future generations; participants with a high school or university degree were more concerned about the future effects of the disaster than those with only elementary studies.

Moreover, participants evaluated the scale of the disaster as high, considering there to be an elevated likelihood of contracting diseases due to the river pollution with a mean score 3.02 (SD = 0.93) over 4. Scores for this variable were unaffected by gender or by educational level.

To observe the extent to which the risk characteristics predict the magnitude of perceived risk, we conducted a stepwise multiple regression analysis with magnitude as the criterion variable and the risk characteristics as predictor variables. The results yield a fit to the model of 22.2% ($R^2 = 0.22$; $F_{(1,217)} = 5.09$; $p = 0.025$). The variables that best predict the perceived risk magnitude are, from the highest to the lowest explained variability: the number of people exposed to the risk; if the risk directly affects the participants; their fear of the risk; the support received by the population to combat the catastrophe; and whether the processes by which the pollution produces diseases are observable (Table 2).

Table 2. Estimate of the magnitude of perceived risk. Predictor and coefficient variables.

	Predictive Variable	B	T	p
	How many people are exposed to the risk? (individuals exposed)	0.310	3.99	0.001
DREAD	How likely are you to be affected by a disease due to the water pollution? (it affects me personally)	0.180	3.04	0.003
	What fear do people have of this risk? (Fear)	0.134	2.30	0.022
	The support given to the population is unevenly distributed	0.128	2.26	0.025
UNKNOWN	The processes through which this water pollution causes disease and damages are (Not observable)	−0.136	−2.49	0.014

In order to determine the degree to which the eleven behaviors recommended by the authorities were categorized by their usefulness in mitigating the effects of the disaster, we conducted a principal axis factor analysis with varimax rotation. This analysis shows that the recommendations are organized in three factors that explain 53.24% of the total variance ($KMO = 0.808$; $\chi^2 = 985.41$, $p < 0.001$). The rotated component matrix (Table 3) shows the weight of the variable in each factor.

Table 3. Factor structure of the 11 behaviors recommended by the authorities.

	Uses of Water	Contact	Actions in the River
Do not use the river water for irrigation of plants, crops or trees.	0.804		
Do not use the river water in drinking troughs for pets or livestock.	0.787		
Do not use the river water for domestic activities.	0.732		
Do not use water pumped from within a radius of 500 m.	0.723		
Close the pumping wells within a radius of 500 m.	0.531		
Avoid contact with the river water.		0.677	
Avoid contact with the riverbank.		0.637	
Do not allow children to play near the riverbank.		0.491	
Change water tanks in schools and houses in affected zones.		0.452	
Separate the soil, rocks and visible sand.			0.804
Dispose of limestone and other products away from the river.			0.761
Explained Variance	33.51	15.04	4.70

Note. All the loads with values below 0.40 have been eliminated, since, to obtain a power level of 80% in the factor analysis with N = 241, the values of the factorial loads are only considered significant from 0.40 [34].

First, factor 1—"uses of water" (33.51% of explained variance)-includes the following recommendations: do not use the river water for irrigation of plants, crops or trees; do not use the river water in drinking troughs for pets or livestock; do not use the river water for domestic activities;

do not use water pumped from within a radius of 500 m; close the pumping wells within a radius of 500 m. All of these factors had loads of between 0.531 and 0.804.

In the second factor—"contact with water" (15.04% of explained variance)—the associated recommendations are, avoid contact with the river water; avoid contact with the riverbank; do not allow children to play near the riverbank; and change water tanks in schools and houses in affected zones. All of them achieved loads of between 0.452 and 0.677.

The variables in the third factor—"actions in the river" (4.70% of explained variance)—which were to separate the soil, rocks and visible sand and dispose of limestone and other products away from the river, have loads of between 0.761 and 0.804.

Finally, we conducted a reliability analysis with direct scores of the responses to the variables of each factor. This yielded a value of $\alpha = 0.863$ for "uses of water", a value of $\alpha = 0.708$ for the dimension of "contact with the water" and a value of $\alpha = 0.803$ for "actions in the river" (Table 4).

Table 4. Univariate statistics of the items referring to behaviors recommended by the authorities.

Variable	*N*	Mean	Standard Deviation	α
USES OF WATER	238	3.23	0.85	0.863
Close the pumping wells within a radius of 500 m.	239	3.33	0.96	
Do not use the river water in drinking troughs for pets or livestock.	240	3.26	1.08	
Do not use water pumped from within a radius of 500 m.	239	3.24	1.04	
Do not use the river water for domestic activities.	240	3.20	1.08	
Do not use the river water for irrigation of plants, crops or trees.	240	3.09	1.14	
CONTACT WITH WATER	234	3.46	0.66	0.708
Do not allow children to play near the riverbank.	239	3.69	0.72	
Avoid contact with the river water.	237	3.56	0.83	
Change water tanks in schools and houses in affected areas.	237	3.40	0.95	
Avoid contact with soil from the riverbank.	239	3.18	1.09	
ACTIONS IN THE RIVER	234	2.52	1.07	0.803
Separate the soil, rocks and visible sand.	238	2.59	1.20	
Dispose of limestone and other products away from the river.	235	2.43	1.15	

In order to verify the degree of perceived usefulness of the three types of behavior, a one factor repeated measures ANOVA was conducted for the behaviors ($F_{(2,182)} = 86.84$, $p < 0.001$, $\eta^2 = 0.49$). The "contact with water" behaviors were perceived as the most useful ($M = 3.46$, $SD = 0.66$), followed by the "uses of water" behaviors ($M = 3.26$, $SD = 0.83$) and, finally, the "actions in the river" behaviors ($M = 2.52$, $SD = 1.07$). The Bonferroni-adjusted pairwise comparisons yielded higher and significantly different scores for "contact with water" behaviors compared to those referring to "uses of water" ($p = 0.001$) and "actions in the river" ($p < 0.001$).

Similarly, comparisons between "uses of water" and "actions in the river" yielded significant differences, with a p value of < 0.001. The gender and educational level variables yielded no significant differences in the assessments of the three types of behavior. Moreover, there were no significant correlations between the evaluation of the recommendations and the magnitude of the perceived risk.

4. Discussion

Participants' perceived fear of the pollution of the river basins is moderate or severe, as all the mean scores of the characteristics in the "psychometric paradigm" are higher than 2. Scores for questions regarding future consequences for the area are especially high; the risk is not easily reduced and will affect future generations. The victims also perceive that resources destined to reducing the damage were unevenly distributed.

Regarding unknown, we can highlight the low level of knowledge of the risk attributed to the scientific world. By contrast, those exposed consider that they have good knowledge of the risk. These results should undoubtedly be considered as two different forms of knowledge; the first relates to scientific and technological aspects, while the second refers to the experience resulting from contact with the polluted water.

With regards to the magnitude of perceived risk, the results show that the respondents estimated the likelihood (3.02 over 4) of contracting a disease due to the spill as high. The characteristics that predicted the magnitude were the number of people who felt they were exposed to the risk of disease, and in the dimension of dread, the characteristics corresponding to personal damage that the accident could cause, fear of the pollution and the uneven distribution of the resources received to fight the catastrophe. With regard to dimension of unknown category, the only characteristic affecting the perceived magnitude was the fact that the processes causing the diseases were not observable.

Together with the quantitative data provided by the psychometric model, it would have been of interest to complement the research with victims' freely expressed opinions on the risks. This would allow us to have a view of the complementary risk, in line with the cultural theory of risk proposed by [35].

Although research suggests that women worry more about risks than men [4,36,37], this difference is barely reflected in the current work, possibly as a result of the undeniable evidence of the catastrophe. Both the obvious manifestations such as the sudden change in the color of the water and the general alarm caused by the intervention of the authorities made the whole population assess the risk in a similar way.

The recommendations made to the general population were evaluated in three dimensions; those related to the use of the water, those related to contact with water, and those involving actions in the river. The results show significant differences between these factors, with participants considering the recommendations on contact with water more useful than those regarding actions in the river. This finding suggests that the victims of the disaster are more willing to accept the usefulness of behaviors related to self-defense than those related to taking action on the disaster.

The results were not only intended for the assessment of the perceived risk of the disaster in the Sonora River basin, as described in this study, but also to help facilitate decision-making by authorities managing these types of catastrophic events. This study suggests that a sudden disaster, such as the one analyzed here, produces a high risk perception, while similar scale water pollution of a chronic character, tend not to produce perceived risk of illness among more deprived populations [5]. Therefore, as suggested by these authors, the uncommon signs of catastrophe were possibly what alerted the population to the disaster, since this type of risk already existed in the Sonora River area, albeit not on the same scale as after the copper spill.

Author Contributions: Juan Ignacio Aragonés and César Tapia-Fonllem Conceived and designed the experiments; Lucía Poggio and Blanca Fraijo-Sing performed the experiments; Juan Ignacio Aragonés and Lucía Poggio analyzed the data; Blanca Fraijo-Sing contributed reagents/materials/analysis tools; Juan Ignacio Aragonés wrote the paper with input from all authors (César Tapia-Fonllem; Lucía Poggio; Blanca Fraijo-Sing).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

What do you think about the pollution of the Sonora River? Answer the following questions:

1. People confront the risk:

- Unwillingly
- Cautiously
- Willingly
- With determination

2. The risk of illness due to the pollution of the Sonora River is:

- Remote
- Not very immediate
- Quite immediate
- Immediate

3. How accurate is people's information about their exposure to risk?

- Inaccurate

- Only slightly accurate
- Quite accurate
- Very accurate

4. How aware are scientists (or science) of this risk?

- Not at all aware
- Slightly aware
- Quite aware
- Fully aware

5. People exposed to this risk:

- Cannot avoid disease
- Can avoid disease with reasonable ease
- Can avoid disease quite easily
- Can avoid disease very easily

6. This risk of water pollution in the Sonora River is:

- Not at all new
- Slightly new
- Quite new
- Very new

7. This risk will make people ill:

- One by one
- In small numbers
- In great numbers
- All at once

8. How likely is this disaster to cause a deadly disease?

- Completely unlikely
- Slightly likely
- Quite likely
- Very likely

9. How afraid are people of this risk?

- Not at all afraid
- Slightly afraid
- Quite afraid
- Very afraid

10. The events that led to this risk were:

- Unforeseeable
- Slightly foreseeable
- Quite foreseeable
- Very foreseeable

11. How many people are exposed to this risk?

- None
- A few
- Quite a lot
- A great number

12. This risk for future generations:

- Poses no threat
- Poses some threat
- Poses quite a threat
- Poses a large threat

13. How likely are you to be affected by the presence of water pollution?

- Unlikely
- Slightly likely
- Quite likely
- Very likely

14. The support given to the population to reduce the negative effects of the pollution of the Sonora River is distributed:

- Unevenly
- Quite unevenly
- Quite evenly
- Very unevenly

15. Do you think that the pollution of the Sonora River could be a catastrophe for the population, causing:

- No illness or death
- Some illness and deaths
- Quite a lot of illness and deaths
- A lot of illness and deaths

16. The processes by which this water pollution causes disease and damage are:

- Invisible
- Slightly visible
- Quite visible
- Very visible

17. Do you think this risk is

- Not increasing
- Increasing a little
- Increasing quite a lot
- Increasing a lot

18. Do you think it is easy to reduce the risk?

- Not easy to reduce
- Somewhat easy to reduce
- Quite easy to reduce
- Very easy to reduce

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