

USE OF INDIGENOUS KNOWLEDGE IN MODELING THE WATER QUALITY DYNAMICS IN PEEPEEKISIS AND KAHKEWISTAHAW FIRST NATIONS COMMUNITIES

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ABSTRACT

Throughout the centuries, every culture has had an intimate and vital connection to water. It is one of the most important elements necessary to sustain life. Civilizations have based their communities in close proximity to water systems for sustenance, cleansing, sacred ceremony and prayer, healing, play and recreation, transport, economics, irrigation of crops and livestock, and unfortunately diluting wastes and contaminants. Each culture has a different way of representing how sacred water is and assigning a unique and intimate value to it. Cultural traditions, Indigenous practices, and societal values are all interconnected in the ways people perceive and manage water throughout the world. Within the reported research project we have developed the Indigenous-knowledge-based method to evaluate water quality and describe the temporal model of water quality dynamics. The method was appropriate for the community water area of Peepeekisis and Kahkewistahaw First Nations situated around the Calling Lakes, Saskatchewan.

Key words: Indigenous knowledge, water quality, environment, modeling

INTRODUCTION

In First Nations communities, water is a very important and sacred element of Mother Earth. It has been represented as a life force or spirit by various Aboriginal groups in human, animal, or supernatural forms. Historically water has been intertwined into First Nations culture and daily life through activities such as hunting and fishing, gathering food and medicines as well as creating a form of livelihood through trapping and fishing.

Within the reported research project we used the years of experience of two First Nation communities (Peepeekisis and Kahkewistahaw) to evaluate the water quality of Calling Lakes. The Calling Lakes consist of the Pasqua, Echo, Mission, and Katepwa Lakes which are part of the Qu'Appelle Valley drainage system in Saskatchewan. These lakes are used by campers, beach goers, and First Nation community members alike who all enjoy and rely on the lake area for recreational activities such as swimming, fishing, boating, and other sporting events. This lake area is also very important to the First Nations groups who hold traditional land in this area as the water and surrounding environment are integral components of both their historical and modern day, cultural, spiritual, and recreational life. Unfortunately this water system has been suspected of contamination, causing recreational water illness (RWI), large summer fish deaths, deformed fish, and considerable algae bloom. The concern regarding the

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water quality came from the members of community administrations, as well as Elders in our private communications. The validity of these concerns was confirmed by the water quality monitoring undertaken by the Saskatchewan Watershed Authority. According to their reports the Water Quality Index for Qu'Appelle River is only about 66% (Saskatchewan Environment, 2007).

The Qu'Appelle Valley drainage system supplies water to nearly a third of the population in the western Canadian prairies. It is, however, characterized by poor water quality, blooms of toxic cyanobacteria, excess plant growth, and significant fish death. Temperature and the level of dissolved oxygen are especially important as these parameters are believed to cause the large numbers of fish deaths seen over these past years in small and shallow lakes in southern Saskatchewan (Saskatchewan Environment, 2007). A significant number of summer fish deaths were observed in July 2007, on Pasqua and Echo Lakes due to a number of factors including: summer heat, little wind, shallow water, and low oxygen levels (Couture, 2007).

Recreational water may be contaminated from a variety of sources including sewage, industrial effluents, agricultural runoff (manure, fertilizers, and pesticides), as well as oil and gasoline spills from boats and marinas. While these chemical contaminants may be detrimental to human health, exposure to disease-causing microorganisms from sewage poses the greatest risk (Health Canada, 2003) and swimming in fecally contaminated waters has consistently been associated with gastrointestinal illness (Wade et al., 2006). In the Qu'Appelle Valley drainage system, the poor water quality is explained by the increase in cropland area, livestock biomass (biological material from living, or recently living organisms), and urban nitrogenous wastes occurring since European settlement (Hall et al., 1999).

Even brief monitoring of water systems used by First Nations communities, show that most of them experience similar problems across Canada. A few years ago, residents of the Kashechewan Reserve in northern Ontario had to leave their homes because of *E. coli* in their drinking water supply, in addition to rashes and other skin problems associated

with their water. This was a result of many years of dynamic negative processes. Modeling of these dynamics processes could predict negative trends, and subsequently prevent negative health and economic outcomes such as those experienced by members of the Kashechewan Reserve. The results of our studies are applicable to First Nations communities, since our methodology uses universal mathematical modeling.

THEORY

The unavailability of western-laboratory-type data on water quality for the areas where the Aboriginal people live, requires developing special evaluation and prognosis-making methodologies. In this work we present an original approach which is based on the traditional knowledge system of Aboriginal people. The developed method can be used for making prognoses based on the traditional knowledge of Aboriginal people living in the areas of the interest.

Careful observation of the world combined with interpretation in various forms is the foundation for Indigenous knowledge (Cruikshank, 2001). The ability to thrive in nature (including in the water) depends in large part on the ability to anticipate and respond to dangers, risks, opportunities, and change. The accuracy and reliability of this knowledge has been repeatedly subjected to the harshest test as people's lives depended on decisions made on the basis of their understanding of the environment. Mistakes can lead to death, even for those with great experience. Thus, information of particular relevance to survival has been valued and refined through countless generations, as individuals combine the lessons of their elders with personal experience (Ingold and Kurtilla, 2000).

Indigenous knowledge is far more than a collection of facts. It is an understanding of the world and of humanity's place in the world. From observations, people everywhere find patterns, similarities, and associations, from which they develop a view of how the world works, a view that explains the mysteries surrounding them and gives them a sense of place (Brody, 2000).

Studies of Indigenous knowledge often make comparisons with scientific knowledge in an effort

to determine the “accuracy” of Indigenous knowledge as measured on a scale that is intended to be objective. However, the idea of validating Indigenous knowledge is a foreign concept to most First Nations people. In fact, Indigenous populations throughout the world have been described as those with a social and cultural identity distinct from the dominant society where they live, who have a close attachment to their ancestral lands. Indigenous societies represent cohesive systems of life, imbued with a shared world view. Every aspect of Indigenous life is governed by sets of rules and values and sustained by a sound knowledge base. Indigenous peoples have achieved harmonious integration with the environment and have sustained this relationship over the centuries (National Aboriginal Health Organization [NAHO], 2003). Here, we argue that mathematical modeling is compatible with Indigenous knowledge.

The emphasis on the cultural aspects of Indigenous knowledge in this assessment is not intended to detract from the great utility it has in ecological and environmental research and management (Berkes, 1998). In this setting, accuracy as evaluated externally may be a key concern because the information is being applied for a purpose that may be very different from that for which it was originally generated.

To apply Indigenous knowledge to environmental research and management, consideration must be given to the ways in which it is acquired, held, and communicated. Indigenous knowledge is the synthesis of innumerable observations made over time (Agrawal, 1995). It is typically qualitative; when quantities are noted, they are more often relative than absolute. Indigenous knowledge evolves with changing social, technological, and environmental conditions, and thus observations of change over time can be influenced by these as well as by the vagaries of memory.

Analysis of our discussions with Elders from the First Nations communities allowed us to conclude that Indigenous knowledge can be used for evaluating the water quality. We also suggest that the Indigenous memory registers the temporal dynamics of the water quality. The thesis forms the basis of the presented research project.

METHODOLOGY

Our research project uses First Nations environment evaluation skills to develop a model for describing water quality dynamics in the First Nations communities. The research proposal was reviewed by the Research Ethical Board of University of Regina and the Research Ethical Board of Health Canada and received the ethical certification of both institutions.

Modeling of nonphysical phenomena is one of the newest areas of Mathematics. There exist a number of methodologies for creating mathematical models in the social, management, and life sciences (for instance, Burghes and Wood, 1984). For real systems it is not easy to collect complete data. This is why some of the existing methodologies relate to the mathematical modeling of systems using incomplete data.

Within the presented research project we used Indigenous environmental memory and community survey information as statistical data. Based on the analysis of the collected statistical data we developed a mathematical model of the temporal dynamics for water quality in Peepeekisis and Kahkewistahaw First Nations communities.

First Nations identify themselves as a part of nature, and they have their own evaluation principles and scale, which they use to determine the current state of nature as a whole as well as its components. In general, evaluation principles are based on beliefs of First Nations. However some principles have quite a materialistic sense, and can be represented quantitatively. To develop the mathematical model we needed to determine key parameters used by First Nations to evaluate the conditions of the water systems.

The key parameters in evaluating the water quality were determined from the interviews of Elders. First we had discussions with the Headman of Peepeekisis band office and the Councillor of Kahkewistahaw band office regarding the goals of our studies. The Headman and the Councillor were determined by their band councils to present their communities in our research project. Six Elders (two from Peepeekisis, four from Kahkewistahaw) were recommended by the Headman (in Peepeekisis)

and the Band Councillor (in Kahkewistahaw). The interviews were taken individually over September 2008, and voice recorded with the permission of Elders. The Elders were asked to explain how they evaluate the water conditions. One has to note that the Elders mainly use the worlds “healthy” and “not healthy” (or sick) regarding the quality of water. The format of the interviews was semistructured.

In analyzing the Elder interviews we determined the parameters to evaluate the water quality in the communities, and developed the following key questions.

1. How would you evaluate the taste of fish caught in your community water in comparison with our days?
2. How would you evaluate overall quality of water in your community in comparison with our days?
3. How would you evaluate the quality of birds hunted in your community in comparison with our days?
4. How would you evaluate the number of bird nests in the shore in comparison with our days?
5. How would you evaluate the level of chemicals of the water in your community in comparison with our days?
6. How often have your family members swimming in the water in your community in comparison with our days?
7. How would you evaluate the transparency of the water in your community in comparison with our days?
8. How do you think the quality of the water in your community will become?

It is typical for the households of First Nations communities to have representatives of 2–3 generations living together. Therefore each household saves in their environmental memories the information regarding the water quality for the last 20–30 years. Considering this potential of First Nations households we decided to address questionnaires to the households, not to individual community members. This idea was supported by the Elders.

The questionnaires, along with the consent forms and return envelopes, were distributed among

120 households of Peepeekisis and 135 households of Kahkewistahaw First Nations over October–November 2008. The questionnaires, consent forms, and return envelopes were distributed by the Headman (in Peepeekisis) and the Councillor (in Kahkewistahaw) who represented their communities in our research project. The householders were given one week to answer the questions. The questionnaires in the sealed envelopes were collected by the Headman (in Peepeekisis) and the Councillor (in Kahkewistahaw). The feedback rate was 35–37%.

In the developed questionnaires the participants were asked to evaluate water quality over the past (30 years, 20 years, 10 years, and 5 years), and to make a prognosis for the future (in 5 years, in 10 years, in 20 years) using the key parameters. To “digitize” the answers we developed the conversion scale presented in Table 1.

Table 1. Digitalization Scale

<i>Answer</i>	<i>Digital Equivalent (Mark)</i>
much better	+2
better	+1
about the same	0
worse	-1
much worse	-2
much more	+2
more	+1
about the same	0
less	-1
much less	-2
much more often	+2
more often	+1
about the same	0
less often	-1
much less often	-2
much more transparent	+2
more transparent	+1
about the same	0
less transparent	-1
not transparent at all	-2

The average marks of each parameter for each time period were evaluated using the following formula,

$$\text{Average mark} = \frac{\sum \text{The mark} \times \text{Number of respondents chosen this mark}}{\text{Total number of respondents}}$$

In the Appendix section we represent how the fish taste was marked by the Peepeekisis commu-

ity for the time period “30 years ago.” A detailed description of the digitalization technique and statistical analysis is presented in Sardarli et al. (2009, 2010; see also the Appendix of this paper).

DISCUSSION

Below we represent the time dependence of the water quality evaluated for Peepeekisis and Kahkewistahaw First Nations communities.

Comparisons of the corresponding plots indicate that the opinions of Peepeekisis and Kahkewistahaw community members regarding the key parameters of the water quality differ slightly. The respondents from both of the communities recognize the negative temporal dynamics of local water quality. This solidarity looks reasonable considering the fact that the communities are situated around the same water area.

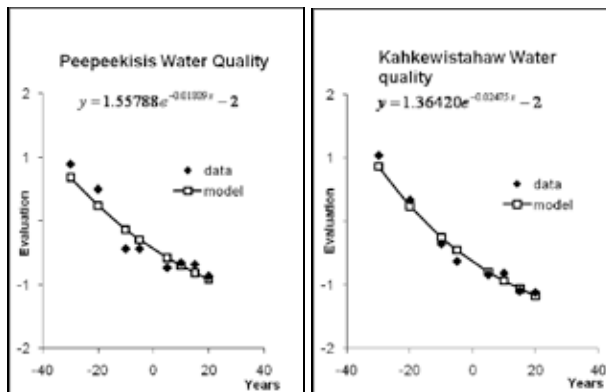


Figure 1 a, b. Temporal Dynamics of Water Quality; Exponential Model

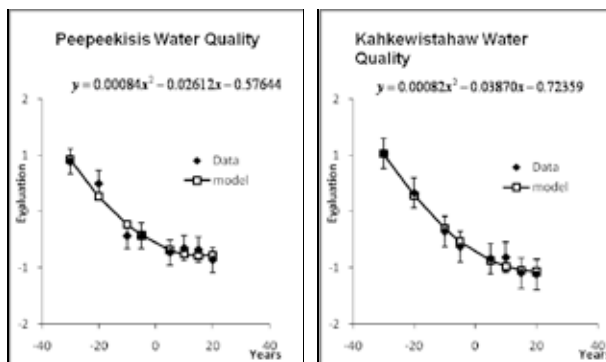


Figure 2 a, b. Temporal Dynamics of Water Quality; Polynomial Model

The community members also notice the rise of chemicals in the water. This result allowed us to conclude that chemicals are considered the main factor

causing a negative trend in water quality. The Elders also noted this consequence in their interviews. The phase diagram Water quality vs. Chemicals represents the influence of chemical use on water quality (Figure 3).

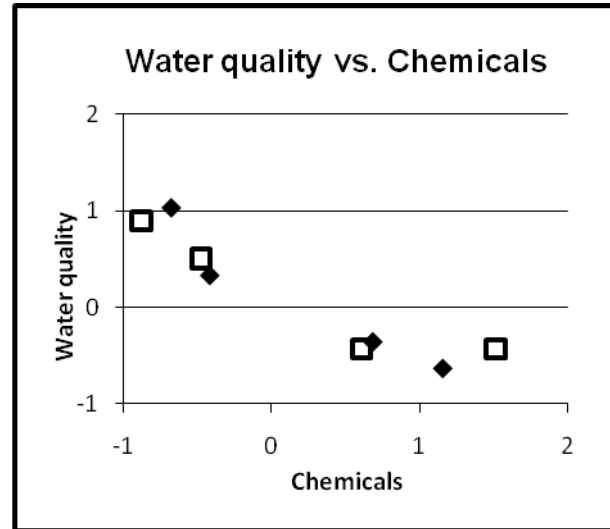


Figure 3. Phase Diagram

Respondents were asked to evaluate overall water quality for the proposed time periods (Questions 2 and 8). One can see that the respondents are more optimistic about the future of the water quality (the year interval 0–40, Figures 1 and 2). Elders explained this by referencing governmental institutions taking more care with water quality in the First Nations communities in recent years. In particular, First Nations community members are aware of the government programs developed for constructing new water treatment facilities, and this fact has affected their answers.

Using suitable mathematical methods we have found two types of functions (exponential and polynomial) that best fit the plots of Figures 1 and 2. Using the least squares method and Microsoft Excel program we determined the functions and the deviations for both of the communities (Table 2).

The mathematical analysis of the polynomials reveals the points of minima in 15 years (in 2024) and in 24 years (in 2033) for Peepeekisis and Kahkewistahaw respectively. The analysis of exponential functions shows that they approach -2 as X approaches infinity. For instance, now the functions are decreasing at the rate of 2.8% per year and 3.3%

Table 2. Best Fitting Functions for the Temporal Dynamics of the Water Quality

Community	Function	Deviation	Minima
Peepeekisis	$y=1.55788e^{-0.01809x}-2$	0.08	—
	$y=0.00084x^2-0.02612x-0.57644$	0.11	15 years
Kahkewistahaw	$y=1.36420e^{-0.02475x}-2$	0.13	—
	$y=0.00082x^2-0.03870x-0.72359$	0.18	24 years

per year for Peepeekisis and Kahkewistahaw respectively. In 25 years (in 2034) the decreasing rates will be 1.8% per year for both of the communities.

Based on the results of the mathematical analysis of the best fitting functions, there are two possible scenarios for the temporal dynamics of the water quality in the Calling Lakes.

POLYNOMIAL SCENARIO

In this scenario, within the next 15–25 years the negative dynamics of water quality will be observed in both of the communities. However if the positive factors (construction of water treatment facilities, restriction of chemical use, etc.) regarding water quality are stimulated at least at the current level, in 15–25 years we may observe the dominating of positive trends in water quality in both communities. Community water is expected to reach the lowest level of quality in 15 (Peepeekisis)–24 (Kahkewistahaw) years. Then, due to water treatment activity, some improvement in water quality may become apparent.

EXPONENTIAL SCENARIO

In this scenario, community water quality will decrease exponentially in spite of water treatment activity until it reaches natural saturation. Though the current rates of decreasing water quality differ in different communities, in 25 years the rate of water quality decreases for both communities will be equal. It is very important to emphasize that the relatively positive scenario can only take place if water treatment programs are carried out on a regular basis.

CONCLUSION

The presented project is one of the pioneering works where First Nations' unique observations and environment evaluation skills are used as a scientific tool for modeling water quality temporal dynamics in a local area.

Within the presented project we developed a methodology to convert First Nations' empiric information into mathematical language. We determined the key parameters following how the First Nations evaluate water quality. We have developed a conversion scale, which allowed us to determine the quantitative equivalent of the qualitative description of the water quality and its temporal dynamics.

The opinions of Peepeekisis and Kahkewistahaw community members regarding the key parameters of water quality in the same water area differ only slightly. This accordance in evaluation indicates the reliability of the developed methodology.

Based on statistical and mathematical analysis we have developed two possible scenarios for the temporal dynamics of water quality. The results of the studies have been reported to the administrations of both communities. In both communities we had meetings with the Elders and other community representatives, within which the results of our studies were presented and discussed in detail. The administrations of the communities indicated high interest in our predictive model and promised to refer to it in their negotiations with interested governmental institutions.

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APPENDIX

DIGITALIZATION CONVERSION FOR THE ANSWERS

1. How would you evaluate the taste of fish caught in your community water in comparison with our days?

30 years ago	20 years ago	10 years ago	5 years ago
much better	much better	much better	much better
better	better	better	better
about the same	about the same	about the same	about the same
worse	worse	worse	worse
much worse	much worse	much worse	much worse

2. How would you evaluate overall quality of water in your community in comparison with our days?

30 years ago	20 years ago	10 years ago	5 years ago
much better	much better	much better	much better
better	better	better	better
about the same	about the same	about the same	about the same
worse	worse	worse	worse
much worse	much worse	much worse	much worse

3. How would you evaluate the quality of birds hunted in your community in comparison with our days?

30 years ago	20 years ago	10 years ago	5 years ago
much better	much better	much better	much better
better	better	better	better
about the same	about the same	about the same	about the same
worse	worse	worse	worse
much worse	much worse	much worse	much worse

4. How would you evaluate the number of bird nests in the shore in comparison with our days?

30 years ago	20 years ago	10 years ago	5 years ago
much more	much more	much more	much more
more	more	more	more
about the same	about the same	about the same	about the same
less	less	less	less
much less	much less	much less	much less

5. How would you evaluate the level of chemicals of the water in your community in comparison with our days?

30 years ago	20 years ago	10 years ago	5 years ago
much more	much more	much more	much more
more	more	more	more
about the same	about the same	about the same	about the same
less	less	less	less
much less	much less	much less	much less

6. How often have your family members been swimming in the water in your community in comparison with our days?

30 years ago	20 years ago	10 years ago	5 years ago
much more often	much more often	much more often	much more often
more often	more often	more often	more often
about the same	about the same	about the same	about the same
less often	less often	less often	less often
much less often	much less often	much less often	much less often

7. How would you evaluate the transparency of the water in your community in comparison with our days?

30 years ago	20 years ago	10 years ago	5 years ago
much more transparent	much more transparent	much more transparent	much more transparent
more transparent	more transparent	more transparent	more transparent
about the same	about the same	about the same	about the same
less transparent	less transparent	less transparent	less transparent
not transparent at all	not transparent at all	not transparent at all	not transparent at all

8. How do you think the quality of the water in your community will become?

In 5 years	In 10 years	In 15 years	In 20 years
much worse	much worse	much worse	much worse
worse	worse	worse	worse
the same	the same	the same	the same
better	better	better	better
much better	much better	much better	much better

EXAMPLE

How would you evaluate the taste of fish caught in your community water in comparison with our days?

Question 1 (30 years ago)	Number of respondents chosen the mark	Mark	Σ
much better	16	2	32
better	5	1	5
about the same	2	0	0
worse	2	-1	-2
much worse	1	-2	-2
	Total number of respondents: 26		Average Mark: 1.27

OR

$$\text{Average Mark} = \frac{2 \times 16 + 5 \times 1 + 2 \times 0 + 2 \times (-1) + 1 \times (-2)}{30} = +1.27$$

This means that the community evaluates the fish taste 30 years ago by the mark of + 1.27 with respect to our days.

All calculations were done using Excel.

STATISTICAL ANALYSIS

Pepeeekisis water survey

Spearman Rank Correlation Coefficient

1. Test the hypothesis of the relationship between how individuals rated the level of chemicals in the water 30 years ago vs. 5 years ago. (Question 5.1 vs. 5.4).

$$H_0: \rho_s = 0$$

$$H_1: \rho_s > 0$$

We will use a significance level of $\alpha=0.05$: d.f. = $n-2=37-2=35$. Therefore, we reject H_0 in favour of H_1 if the test statistic $t > 1.691$. Otherwise fail to reject H_0 .

$$r_s = 1 - \left[\frac{6 \sum D^2}{n(n^2 - 1)} \right] = 1 - \left[\frac{6(267)}{37(37^2 - 1)} \right] = 0.968$$

$$t = r_s \sqrt{\frac{n-2}{1-r_s^2}} = 0.968 \sqrt{\frac{37-2}{1-0.968^2}} = 22.952$$

Since $t = 22.952$ is greater than 1.691, the null hypothesis is rejected. We can conclude that there is a strong positive relationship between respondents' evaluations of the level of chemicals in the water 30 years ago versus his/her evaluation of the level of chemicals 5 years ago. The majority of respondents rated the level of chemicals in the water lower 30 years ago in comparison to 5 years ago.

2. Test the hypothesis of the relationship between how individuals rated the water quality 30 years ago vs. 20 years into the future. (Question 2.1 vs. 8.4).

$$H_0: \rho_s = 0$$

$$H_1: \rho_s > 0$$

We will use a significance level of $\alpha = 0.05$: d.f. = $n-2=37-2=35$. Therefore, we reject H_0 in favor of H_1 if the test statistic $t > 1.691$. Otherwise fail to reject H_0 .

$$r_s = 1 - \left[\frac{6 \sum D^2}{n(n^2 - 1)} \right] = 1 - \left[\frac{6(204)}{37(37^2 - 1)} \right] = 0.976$$

$$t = r_s \sqrt{\frac{n-2}{1-r_s^2}} = 0.976 \sqrt{\frac{37-2}{1-0.976^2}} = 26.411$$

Since $t = 26.411$ is greater than 1.691, the null hypothesis is rejected. We can conclude that there is a strong positive relationship between respondents' evaluations of the water quality 30 years ago versus his/her evaluation of the water quality 20 years into the future. The majority of respondents rated the quality of water healthier 30 years ago in comparison to 20 years into the future.

Kahkewistahaw water survey

Spearman Rank Correlation Coefficient

1. Test the hypothesis of the relationship between how individuals rated the level of chemicals in the water 30 years ago vs. 5 years ago. (Question 5.1 vs. 5.4).

$$H_0: \rho_s = 0$$

$$H_1: \rho_s > 0$$

We will use a significance level of $\alpha = 0.05$: d.f. = $n-2 = 38-2 = 36$. Therefore, we reject H_0 in favor of H_1 if the test statistic $t > 1.689$.

$$r_s = 1 - \left[\frac{6 \sum D^2}{n(n^2 - 1)} \right] = 1 - \left[\frac{6(267)}{38(38^2 - 1)} \right] = 0.971$$

$$t = r_s \sqrt{\frac{n-2}{1-r_s^2}} = 0.971 \sqrt{\frac{38-2}{1-0.971^2}} = 24.274$$

Since $t = 24.274$ is greater than 1.689, the null hypothesis is rejected. We can conclude that there is a strong positive relationship between respondents' evaluations of the level of chemicals in the water 30 years ago versus his/her evaluation of the level of chemicals 5 years ago. The majority of respondents rated the level of chemicals in the water lower 30 years ago in comparison to 5 years ago.

2. Test the hypothesis of the relationship between how individuals rated the water quality 30 years

ago vs. 20 years into the future. (Question 2.1 vs. 8.4).

$$H_0: \rho_s = 0$$

$$H_1: \rho_s > 0$$

We will use a significance level of $\alpha = 0.05$: d.f. = $n-2 = 38-2 = 36$. Therefore, we reject H_0 in favor of H_1 if the test statistic is $t > 1.689$.

$$r_s = 1 - \left[\frac{6 \sum D^2}{n(n^2 - 1)} \right] = 1 - \left[\frac{6(206)}{38(38^2 - 1)} \right] = 0.977$$

$$t = r_s \sqrt{\frac{n-2}{1-r_s^2}} = 0.977 \sqrt{\frac{38-2}{1-0.977^2}} = 27.779$$

Since $t = 27.779$ is greater than 1.689, the null hypothesis is rejected. We can conclude that there's a strong positive relationship between respondents' evaluations of the water quality 30 years ago versus his/her evaluation of the water quality 20 years into the future. The majority of respondents rated the quality of water healthier 30 years ago in comparison to 20 years into the future.

Dr. Arzu Sardarli is an associate professor of Physics and Mathematics in the Department of Interdisciplinary Programs at First Nations University of Canada. His current research interests are: mathematical modeling of environmental processes; seasonal behaviour of fertility patterns; and quantum phenomena in semiconductor materials with low-dimensional crystalline structure. He is also a coordinator of the Wiseman Mathematics Contest for First Nations schools in Canada, a project which is supported by Natural Sciences and Engineering Research Council of Canada.

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