The relationship between concerns of local issues and water conservation behaviors: Insights from Albuquerque, New Mexico, USA

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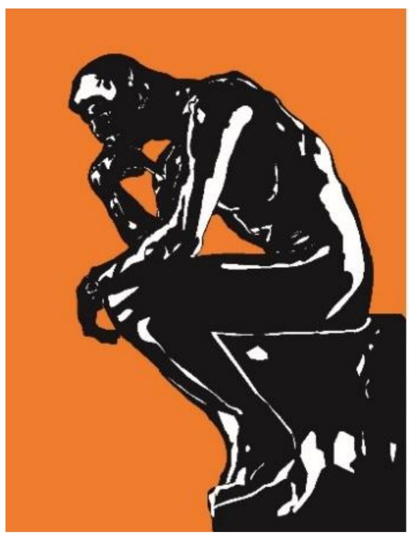

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"Nightingale feeds himself sumptuously, gets thirsty, then goes inside the cage. Just when he is drinking the water, the door shuts down. A once-free bird is now a prisoner".

— In "Dream"; *The Kingfisher Story Collection* [1]

Abstract

With growing global concerns about water scarcity and environmental sustainability, understanding the factors influencing individual water conservation behaviors is crucial. This study utilizes the Bayesian Mindsponge Framework (BMF) analytics to investigate the relationship between concerns of local issues and water conservation behaviors in a sample of 1831 residents in Albuquerque, New Mexico, USA. New Mexico is an arid region of which 90% faced severe drought driven by the most significant wildfire in state history and some of the driest months ever recorded in 2022. The results show a positive association between the drought or water scarcity concern and the number of water conservation behaviors adopted. Likewise, the positive association between the concern about population growth and development and water conservation behaviors is also observed. However, further examination is needed due to the weak reliability of this relationship. In contrast, negative associations between concerns about water quality and water bills with water conservation behaviors are also identified. Based on these findings, the study discusses the potential of building the eco-surplus culture by improving information dissemination of water-saving methods and existing water-related issues in the local areas.

Keywords: water management, drought, arid region, Mindsponge Theory

1. Introduction

Water, a fundamental component of economic, environmental, and social well-being, is essential for human survival [2]. The growing water demand, driven by urbanization, industrialization, population growth, and economic development, has raised alarming concerns about the depletion of global water resources [3].

The challenges caused by water scarcity are becoming increasingly urgent, with urban residents expected to encounter increased difficulties by the year 2050. A report by UNESCO on behalf of UN-Water [4] estimates that 26% of the global population, approximately 2 billion individuals, lack access to clean drinking water. Additionally, 46% of the population, around 3.6 billion people, do not have access to adequately managed sanitation facilities. Projections indicate that the number of urban residents worldwide experiencing water scarcity may double, ranging from 1.7 to 2.4 billion by 2050. Prolonged droughts further strain ecosystems and substantially affect various plant and animal species [4]. In the United States, households contend with distinct challenges related to water [5], including inadequate plumbing infrastructure, water quality issues [6], and a significant portion of community water systems failing to meet established regulations.

Addressing environmental sustainability challenges, changing climate patterns, and the urgent need for water conservation have become important. Whether at the individual or community level, adopting water conservation practices is essential for mitigating the consequences of water scarcity and promoting responsible water management [7].

The existing body of research extensively explores the connection between individuals' concerns about local issues and their involvement in water conservation behaviors, as evidenced by studies conducted by Chang [8], Gilbertson*, et al.* [9], and Hannibal*, et al.* [10]. These studies underscore the impact of various contextual factors, such as water scarcity due to drought and local source depletion [11,12], increased demand [13], and concerns about water quality, encompassing contamination and pollution, play a crucial role in motivating individuals to engage in water conservation efforts [14]. Financial incentives, particularly related to water bills and concerns for the well-being of the community, encompassing agriculture, local ecosystems, and community welfare, have been identified as strong drivers for water conservation efforts [10]. This underscores the significance of taking local conditions into account when implementing proactive water-saving measures.

However, despite these insights, a research gap persists in the existing literature about the impact of individual concerns of local issues on water conservation behaviors. This gap is particularly pronounced in Albuquerque, New Mexico, USA, which faces worsening drought and historic aridity. It was reported that in 2022, more than 90% of the region suffered from severe drought driven by the greatest wildfire in state history and some of the driest months ever recorded [15,16]. Drinking water in Albuquerque is mainly supplied by the Rio Grande and Colorado River. However, in 2022, two of the nation's largest water reservoirs, Lake Mead and Lake Powell, which the Colorado River supplies, reached record lows, while the Rio Grande went dry for the first time in 40 years [17]. The situation is anticipated to be more dire as climate change intensifies. Although several studies have been conducted to study water knowledge, trust, and potable reuse in this region [18-20], understanding of factors influencing water conservation behaviors remains limited.

Our study addresses this research gap by employing the Bayesian Mindsponge Framework (BMF) analytics on 1831 water-utility account holders from Albuquerque, New Mexico, USA. It delves into the relationship between residents' concerns about local issues and their water conservation behaviors through the cognitive perspective.

The anticipated impact of this research is significant for advancing the development and promotion of "eco-surplus culture". This cultural paradigm, representing the 11th progressive cultural value in addition to 10 progressive cultural values proposed by Harrison and Huntington [21], signifies a transformative shift towards environmental stewardship and sustainability [22]. Emphasizing the preservation of ecological balance and advocating for the generation of additional benefits for the environment, eco-surplus culture is rooted in the belief that individual and collective actions can actively contribute to positive environmental impacts, making it particularly relevant for addressing challenges like water scarcity, climate change, and biodiversity loss [23-25].

2. Methodology

2.1. Theoretical foundation

2.1.1. Overview of the Mindsponge Theory

The theoretical foundation for constructing models in this study is the Mindsponge Theory. Initially developed as the mindsponge mechanism by Vuong and Napier [26], it explains how top managers absorb new values and discard waning ones from their mindset. The concept of "mindsponge" draws an analogy between the mind and a sponge, expelling unsuitable values and absorbing new ones compatible with core values [26]. Based on new evidence in life, neuro, and ecological sciences, the mechanism was expanded into the Mindsponge Theory [27], offering a dynamic perspective on the cognitive process of the human mind through the information-processing lens.

Within the Mindsponge Theory, the mind and the surrounding environment are integral components. The mind consists of three identified components: the mindset, the buffer zone, and the multi-filtering system. The mindset comprises highly trusted information, essentially constituting core values. The buffer zone functions as a temporary storage area for information, while the multi-filtering system integrates or differentiates information based on the benchmarks of core values, determining whether to accept, reject, or store it in the buffer zone for later evaluation.

The dynamic interactions between the human mind and its surrounding environment are fundamental to cognitive processes and behavioral patterns, allowing the mind to adapt and evolve in response to external stimuli and changing circumstances. This dynamic relationship underscores that human minds are not static; they can adjust, learn, and incorporate new information based on experiences and interactions with the world [28-30].

This foundational idea sets the stage for the potential transformation of one's mindset, encompassing beliefs, attitudes, and thought patterns. When confronted with new information or shifts in environmental conditions, the mind has the capacity to reassess and recalibrate its perspectives.

2.1.2. Proposed assumptions

In addressing environmental challenges, such as water scarcity, the recognition of the significance of water to human life emerges as a pivotal factor. As individuals become more concerned about information related to water shortage, this concern becomes integrated into their mindset, actively influencing subsequent thinking and behavior. Once absorbed into the mindset, the concern of water scarcity acts as a guiding force, shaping subsequent information-filtering processes, decisions, and actions related to water conservation. In other words, recognizing water scarcity can catalyze enduring changes in thinking and actions, fostering a proactive approach towards responsible water use and conservation practices.

Examined through the mindsponge framework, residents' concern about water-related issues functions akin to the information stored within the mind. Suppose such information, particularly concerns about local issues related to water (e.g., drought, human population, water bills, and water quality), becomes highly trusted information stored in the mindset. In that case, information associated with local issues will act as references based on which people interpret, evaluate, and respond to information about water scarcity, subsequently influencing how individuals perceive the act of water conservation to maximize perceived benefits or minimize perceived costs.

Following this reasoning, concerns of water-related local issues are deemed as potential predictors of water conservation behaviors among water-utility account holders from Albuquerque. In the questionnaire designed by Distler and Scruggs [31], concerns about eight local issues were asked: 1) drought/water shortage, 2) quality of public education in local schools, 3) population growth and development, 4) jobs and the local economy, 5) crime rate, 6) the amount paid in local taxes, 7) local drinking water quality, and 8) the amount paid on water bill. Among these eight issues, drought/water shortage, population growth and development, local drinking water quality, and the amount paid on water bills were included in our statistical model to test whether the concern of water-related local issues is associated with water conservation behaviors. These issues were selected as they were directly related to water usage.

2.2. Construction of the model

2.2.1. Selection of variables

The data utilized in this study originated from an extensive public survey deployed via mail to a randomly selected sample of 4000 water-utility account holders in Albuquerque, New Mexico, USA. The survey was conducted by Distler and Scruggs [31] in partnership with the Albuquerque Bernalillo County Water Utility Authority (ABCWUA) to capture insights into water knowledge, consumption habits, attitudes toward water-related issues, and demographic information. The dataset and its comprehensive description, peer-reviewed and published in Data in Brief [31], have been previously employed in studies focusing on water consumption behaviors in Albuquerque, New Mexico [18-20]. The survey comprised four versions, differing only in educational content related to water reuse on page five.

To design the survey, eight focus groups and 12 debriefing sessions were conducted with individual members of the studied population. Participants who were aged 18 or older and ABCWUA clients actively engaged in testing prototype survey questions within focus groups and provided valuable feedback in subsequent debriefing sessions.

Drawing a random sample of 4000 accounts from over 180,000 residential accounts ensured proportions closely mirrored those in the overall customer accounts database. The survey, administered through mail and Survey Monkey, garnered 1831 responses, resulting in a 46% response rate.

In the present study, we employed five variables to construct the model, including one outcome variable and four predictor variables. The outcome variable, *WATER_CONSERVATION*, functions as an indicator of respondents' support for water conservation practices. To comprehensively address the research objective, we integrated four predictor variables capturing respondents' concerns: *DROUGHT_CONCERN*, *POPULATION_CONCERN*, *WATERBILL_CONCERN*, and *WATERQUALI_CONCERN*. These variables offer insights into the extent to which respondents express consideration regarding drought, human population growth and development, water bills, and water quality, respectively.

WATER_CONSERVATION is the outcome variable representing the number of water conservation behaviors the water users were doing at home. The variable was generated by summing six variables: *CONSERVE_XERI* (i.e., xeriscaped land/yard), *CONSERVE_YARD* (i.e., do not water land/yard), *CONSERVE_FIXTURES* (i.e., use water saving fixtures, like faucets, toilets, etc.), *CONSERVE_APPLIANCES* (i.e., use water-efficient appliances, like dishwasher, washing machine, etc.), *CONSERVE_RAINWATER* (i.e., practice rainwater harvesting), and *CONSERVE_SIMPLE* (i.e., use simple conservation measures, like turning off water when brushing teeth, etc.). The higher the number, the more water conservation behaviors the water user conducted. Descriptions of other variables are shown in Table 1.

Table 1. Variable description.

Variable	Description	Type of Variable	Value
WATER_CONSERVATION	The number of water conservation behaviors that the respondent was doing at home at the time of being surveyed	Numerical	Min = 1 Max = 6
DROUGHT_CONCERN	Level of concern with drought/water shortage	Numerical	1. Not at all concerned 2. Slightly concerned 3. Moderately concerned

			4. Very concerned 5. Extremely concerned
POPULATION_CONCERN	Level of concern with population growth and development	Numerical	1. Not at all concerned 2. Slightly concerned 3. Moderately concerned 4. Very concerned 5. Extremely concerned
WATERBILL_CONCERN	Level of concern with amount paid on water bill.	Numerical	1. Not at all concerned 2. Slightly concerned 3. Moderately concerned 4. Very concerned 5. Extremely concerned
WATERQUAL_CONCERN	Level of concern with local drinking water quality	Numerical	1. Not at all concerned 2. Slightly concerned 3. Moderately concerned 4. Very concerned 5. Extremely concerned

2.2.2. Statistical model

To investigate the connection between individuals' concern of water-related local issues and water conservation behaviors, we formulated Model 1 with the following structure:

$$WATER\_CONSERVATION \sim normal(\mu, \sigma) \quad (1.1)$$

$$\mu_i = \beta_0 + \beta_1 * DROUGHT\_CONCERN_i + \beta_2 * POPULATION\_CONCERN_i + \beta_3 * WATERBILL\_CONCERN_i + \beta_4 * WATERQUAL\_CONCERN_i \quad (1.2)$$

$$\beta \sim normal(M, S) \quad (1.3)$$

The probability around μ is determined by the form of the normal distribution, where the width is specified by the standard deviation σ. μ_i represents the number of water conservation behaviors exhibited by water user i; $DROUGHT\_CONCERN_i$ indicates water user i's level of concern about drought/water shortage; $POPULATION\_CONCERN_i$ indicates water user i's level of concern about population growth and development; $WATERBILL\_CONCERN_i$ indicates water user i's level of concern about the amount paid on the water bill; $WATERQUAL\_CONCERN_i$ indicates water user i's level of concern about local drinking water quality. Model 1 has six parameters: the coefficients, (β_1 – β_4), the intercept, β_0, and the standard deviation of the "noise", σ. The coefficients of the predictor variables are distributed as a normal distribution around the mean denoted M and with the standard deviation denoted S. The logical network of Model 1 is shown in Figure 1.

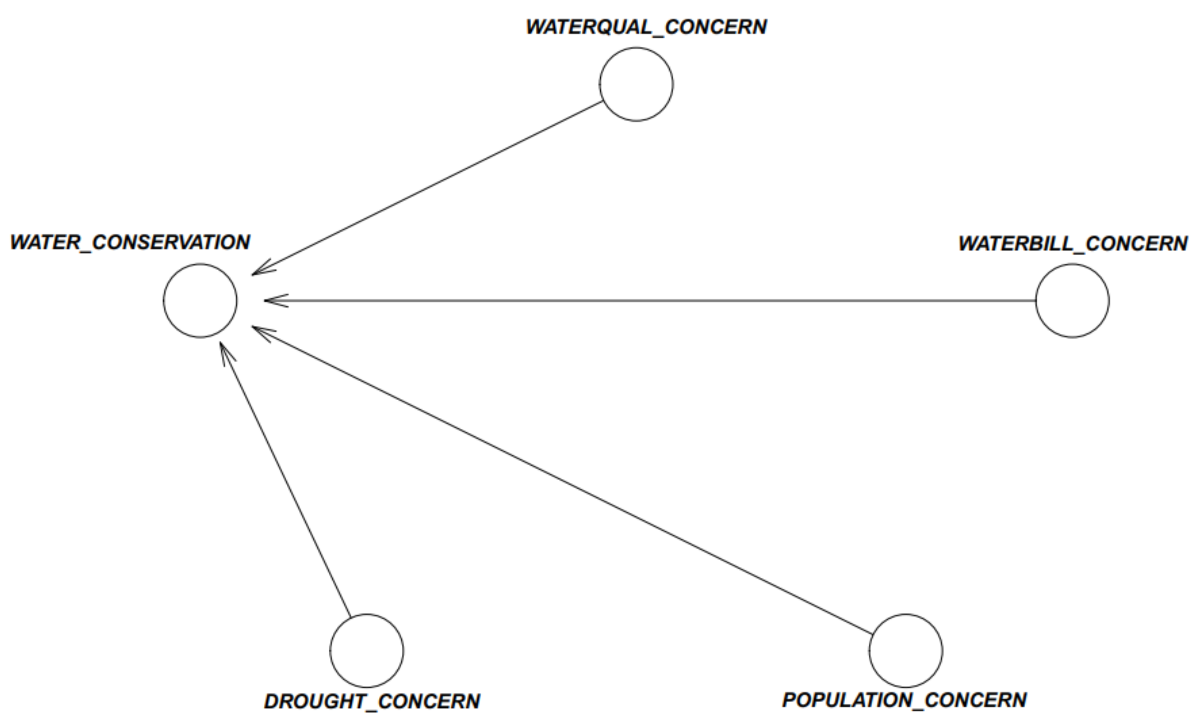

Figure 1: Model 1's logical network

2.3. Analysis and validation

The choice of the Bayesian Mindsponge Framework (BMF) for the analytical approach in this study was underpinned by the integration of the advantageous features of Mindsponge Theory with Bayesian analysis, providing flexibility across cognitive, psychological, and social research areas [28,32]. This choice is motivated by several key considerations.

First, BMF takes advantage of the logical strengths inherent in Mindsponge Theory, combining them with the inferential advantages of Bayesian analysis [32]. Secondly, the Bayesian inference considers all attributes probabilistically, enabling the generation of parsimonious models that enhance overall predictability [33,34]. Thirdly, Bayesian inference empowers users to interpret results using credible intervals, steering away from the dichotomous decisions based on *p*-values that have been implicated in the reproducibility crisis [35,36]. This shift in interpretation method contributes to the reliability and transparency of the study's findings.

Subsequent to model construction, the study employs Pareto-smoothed importance sampling leave-one-out (PSIS-LOO) diagnostics to assess model fit. This approach, following the methodology outlined by Vehtari and Gabry [37] and Vehtari*, et al.* [38], gauges the well-fitted nature of the model by ensuring k values fall below 0.5.

$$LOO = -2LPPD_{LOO} = -2\sum_{i=1}^{n} log\int p(y_i|\theta)p_{post(-i)}(\theta)d\theta$$

The posterior distribution, represented as $p_{post(-i)}(\theta)$, is computed based on the dataset minus data point i.

Ensuring the statistical convergence of Markov chains is a critical step in the Bayesian analysis. The evaluation, utilizing effective sample size (*n_eff*) and Gelman–Rubin shrinks factor (*Rhat*), to assess whether the simulated posteriors using the Markov chain Monte Carlo (MCMC) technique are technically reliable and eligible for interpretation. In other words, these two statistical values are used to evaluate if the Markov chains are convergent. The convergence is affirmed when the *n_eff* exceeds 1000 and *Rhat* equals 1. The Markov chain convergence is also validated by trace plots, Gelman-Rubin-Brooks plots, and autocorrelation plots.

The bayesvl R package is employed for Bayesian analysis [39], and the dataset, data description, and code snippets are openly shared on The Open Science Framework for transparency and future replication [40]: https://osf.io/p5q3g

3. Results

Before interpreting the results, it is necessary to assess Model 1's goodness of fit with the data. As seen in Figure 2, all the estimated k-values are below the 0.5 threshold, indicating a good signal of fit between the model and the data.

The statistics of Model 1's posterior distributions are shown in Table 2. All the *n_eff* values are larger than 1000, and *Rhat* values are equal to 1, so it can be deemed that Model 1's Markov chains are well-convergent. The convergence of Markov chains is also reflected through the trace plots in Figure 3. Specifically, all the chains' values fluctuate around a central equilibrium after the 2000th iteration.

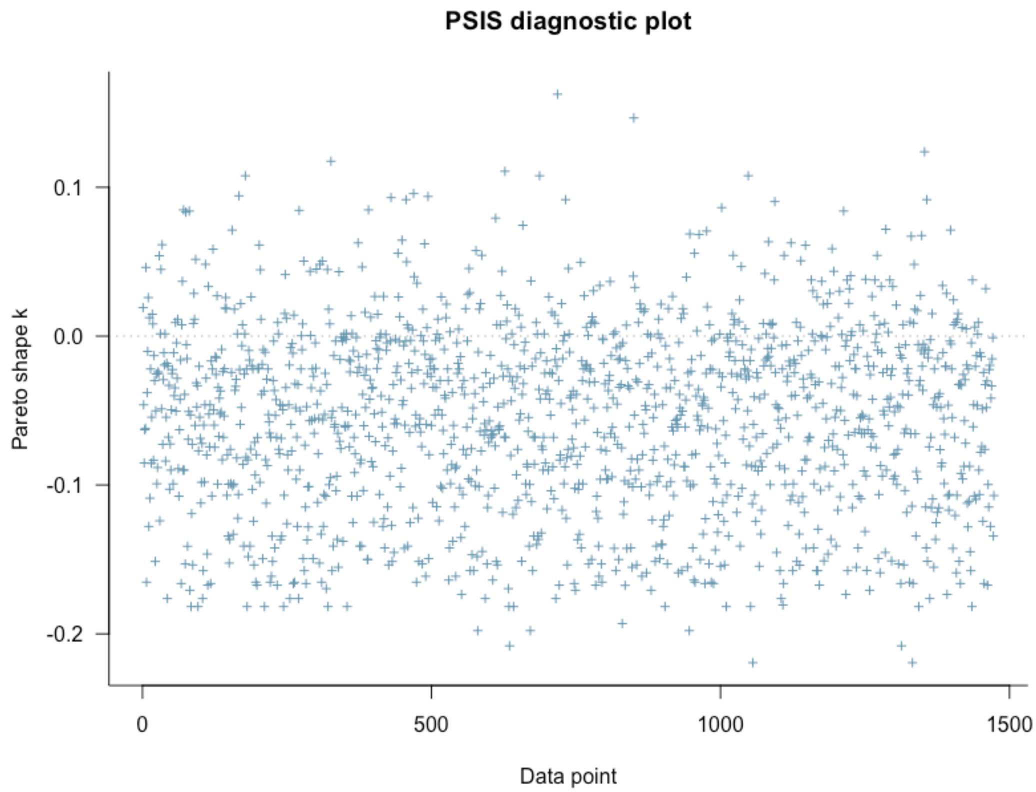

Figure 2: Model 1's PSIS-LOO diagnosis

Table 2: Estimated results of Model 1

Parameters	Mean	SD	n_ff	Rhat
Constant	2.49	0.14	8030	1
DROUGHT_CONCERN	0.26	0.04	8840	1

POPULATION_CONCERN	0.02	0.03	10012	1
WATERBILL_CONCERN	-0.14	0.03	9176	1
WATERQUAL_CONCERN	-0.03	0.03	9194	1

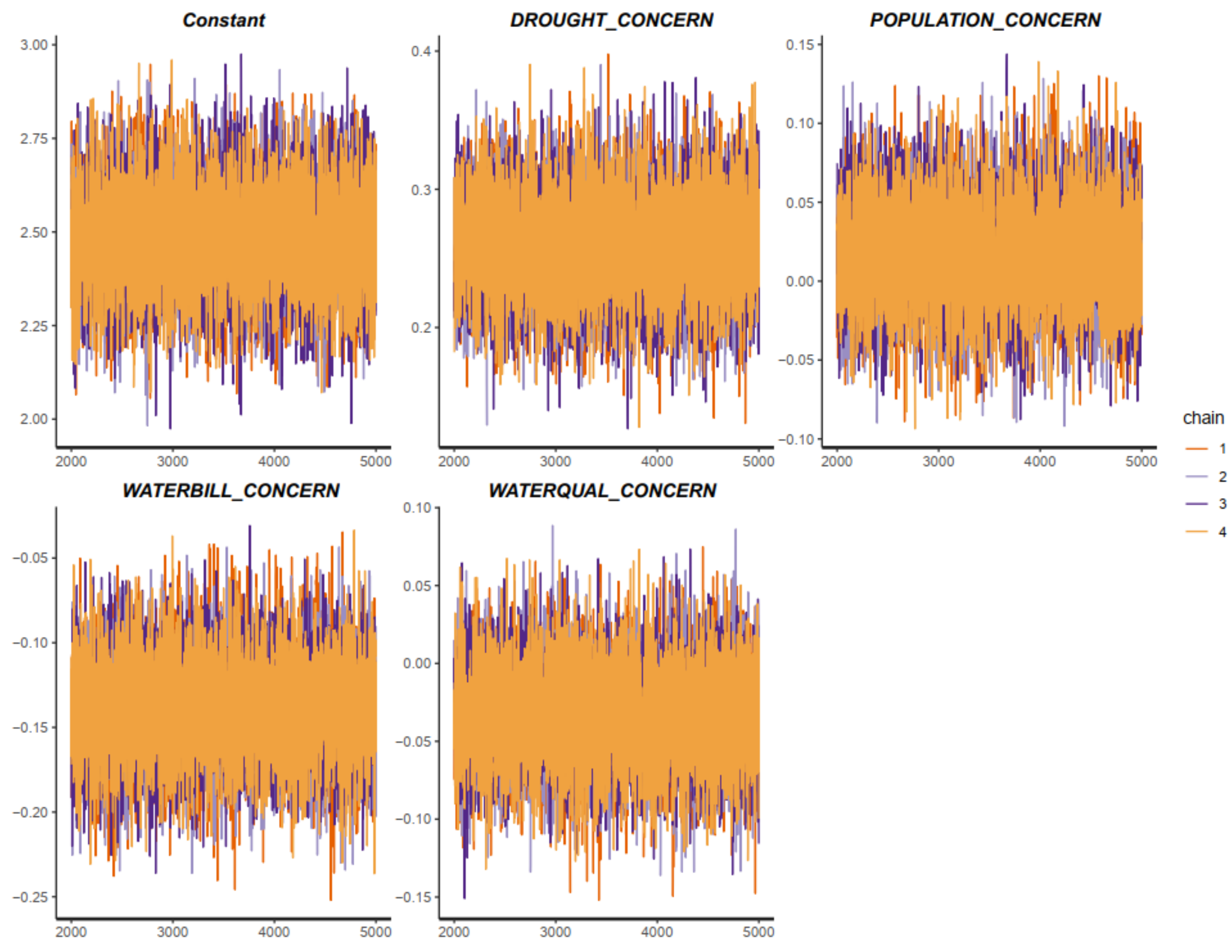

Figure 3: Model 1's trace plots

The Gelman-Rubin-Brooks plots and autocorrelation plots also signify the good convergence of Markov chains. The Gelman-Rubin-Brooks plots are used to assess the ratio between the variance between Markov chains and the variance within chains. The *y*-axis illustrates the shrink factor (or Gelman-Rubin factor), while the *x*-axis demonstrates the iteration order of the simulation. In Figure 4, the shrink factors of all parameters drop rapidly to 1 before the 2000th iteration (within the warmup period). This manifestation suggests that there is no divergence among Markov chains.

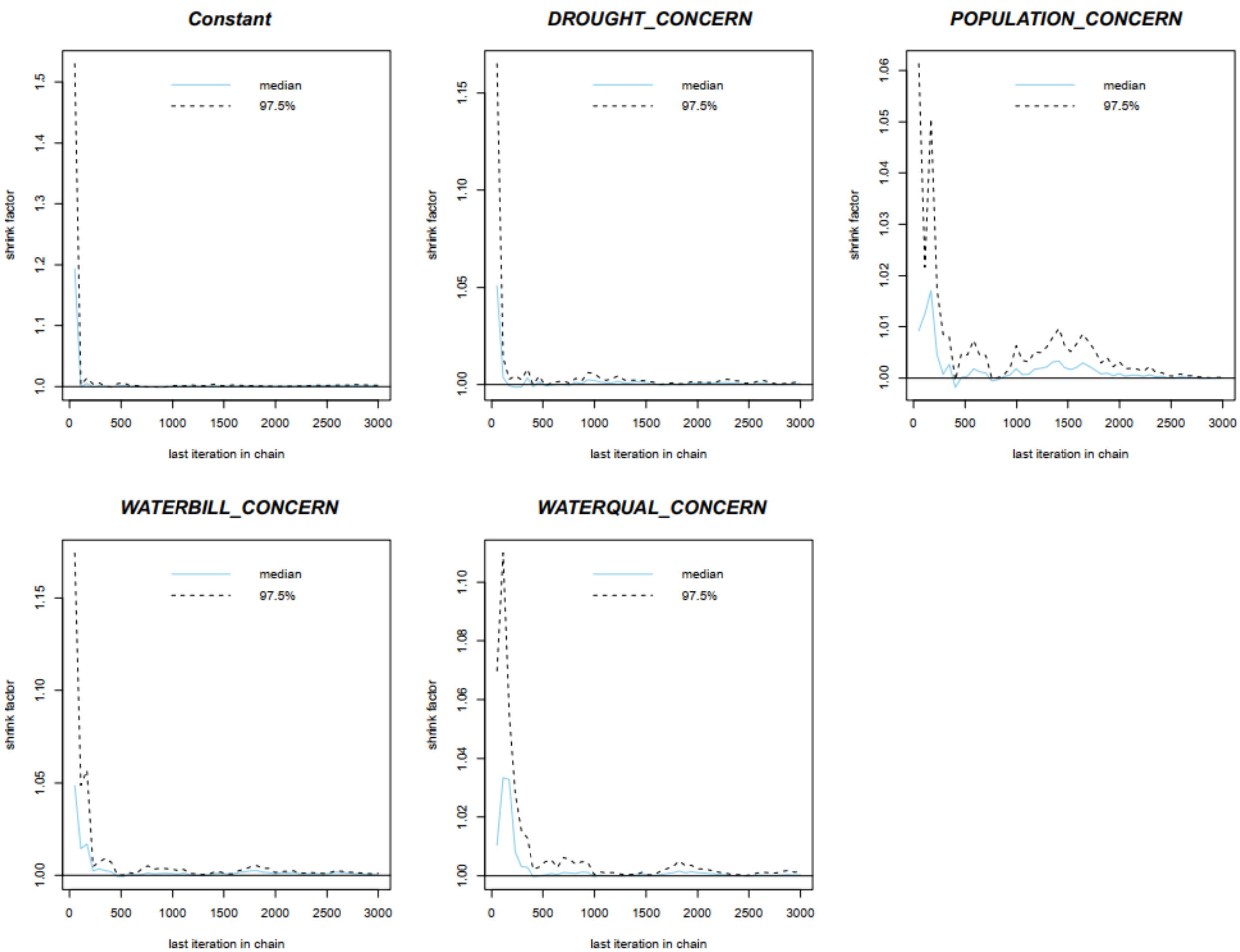

Figure 4: Model 1's Gelman-Rubin-Brooks plots

For the simulated posteriors to be interpreted, the simulated values must hold the Markov property, which refers to the memoryless property of a stochastic process. In other words, the iteration values are not autocorrelated with the past iteration values. The autocorrelation plots are employed to evaluate the autocorrelation levels among iteration values. The charts in Figure 5 show the aggregate autocorrelation level of each Markov chain along the *y*-axis and the lag of the chains along the *x*-axis. Visually, all the Markov chains' autocorrelation levels decline swiftly to 0 after a few numbers of lags (before 5), suggesting that the Markov property is held and the Markov chains are well-convergent.

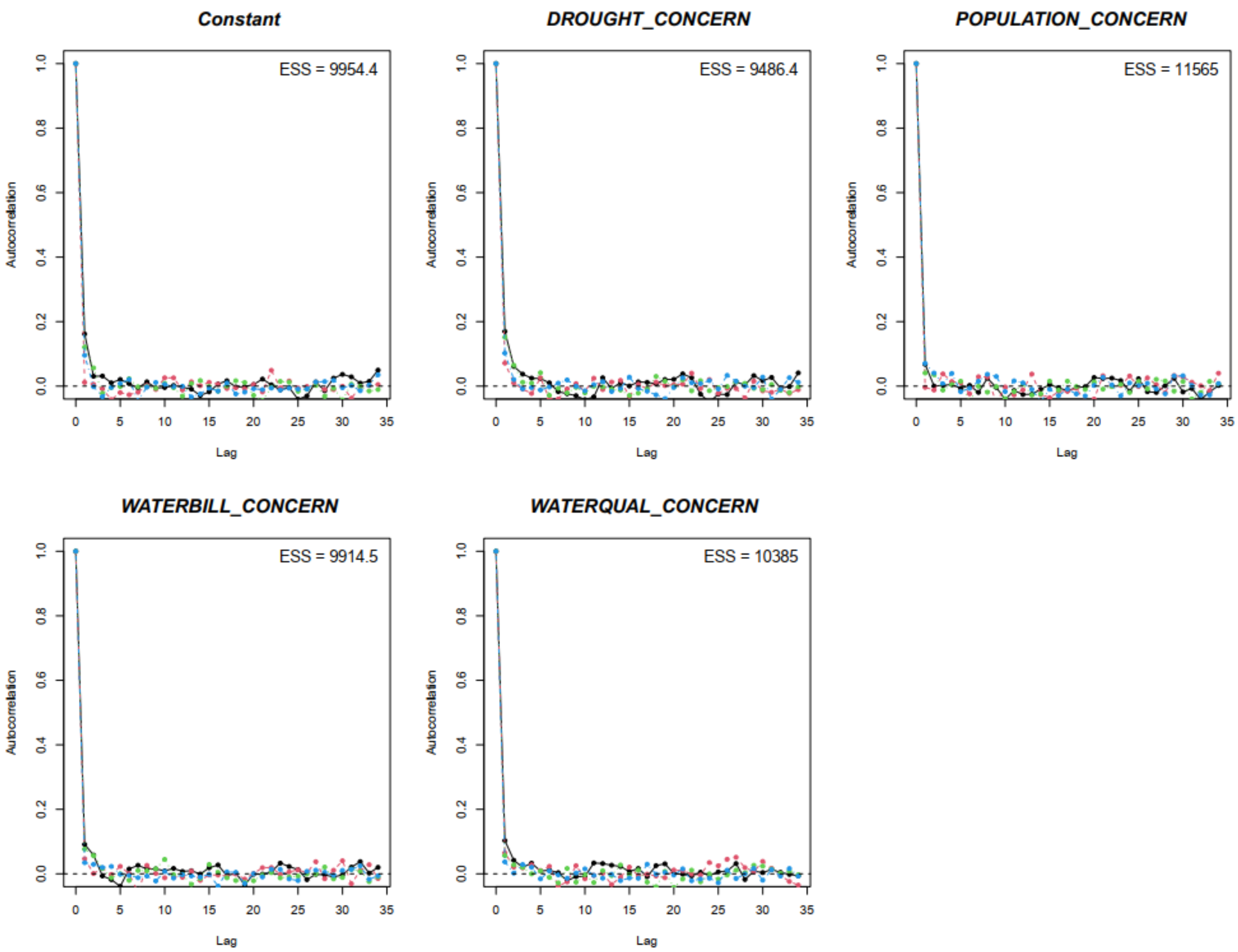

Figure 5: Model 1's autocorrelation plots

Since all the diagnostics confirm the convergence of Markov chains, the simulated results are eligible for interpretation. The estimated results of Model 1 show that residents' concerns about drought/water shortage and population growth are positively associated with their number of water conservation behaviors ($M_{DROUGHT\_CONCERN}$ = 0.26 and $S_{DROUGHT\_CONCERN}$ = 0.04; $M_{POPULATION\_CONCERN}$ = 0.26 and $S_{POPULATION\_CONCERN}$ = 0.04). In contrast, concerns about water quality and water bills are negatively associated with the number of water conservation behaviors ($M_{WATERBILL\_CONCERN}$ = -0.14 and $S_{WATERBILL\_CONCERN}$ = 0.03; $M_{WATERQUAL\_CONCERN}$ = -0.03 and $S_{WATERQUAL\_CONCERN}$ = 0.03).

Figure 6 illustrates all the posterior distributions with their 89% Highest Posterior Density Interval (HPDI). The black line in the middle of each chart displays the HPDI of each distribution. It can be seen that while the HPDI of $DROUGHT\_CONCERN$ lies entirely on the positive side of the *x*-axis, a large portion of $POPULATION\_CONCERN$'s HPDI is still located on the negative side. These illustrations suggest that the positive effect of $DROUGHT\_CONCERN$ is highly reliable, whereas that of $POPULATION\_CONCERN$ is weakly reliable. The HDPI of $WATERBILL\_CONCERN$ is located entirely on the negative side, while a small portion of $WATERQUAL\_CONCERN$'s HPDI still lies on the positive side. This implies that the negative effect of $WATERBILL\_CONCERN$ is highly reliable, whereas that of $WATERQUAL\_CONCERN$ is moderately reliable.

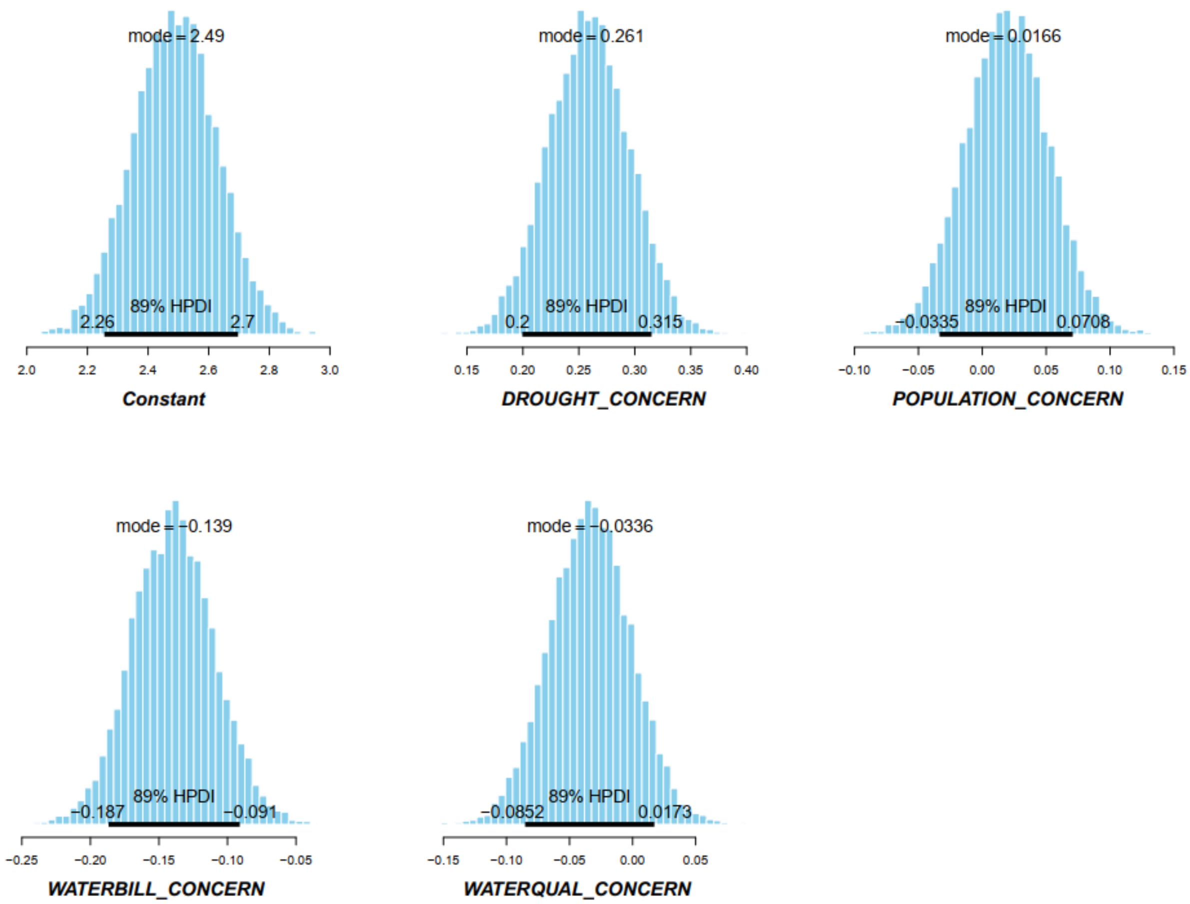

Figure 6: Model 1's posterior distributions with 89% HPDI

4. Discussion

The research employed Bayesian Mindsponge Framework analytics to delve into the intricate relationship between local concerns and water conservation behaviors, yielding significant findings. Focusing on Albuquerque, New Mexico, the study acknowledges the region's distinct challenges related to aridity and economic dependence on water resources. Analyzing data from 1831 residents in New Mexico, USA, revealed a positive correlation between residents' concerns about drought or water shortage in Albuquerque, Bernalillo County, and the frequency of their water conservation behaviors. This finding highlights the substantial impact of environmental factors on individual behavior, aligning with the initial hypotheses and emphasizing a strong correlation between the perception of water scarcity or drought and proactive measures to conserve this important resource[41,42].

Furthermore, there exists a positive association between local concerns about population growth and development and the number of water conservation behaviors among residents in Albuquerque. However, the weak reliability of this relationship underscores its complexity and inconsistency compared to other variables. The multifaceted nature of concerns related to population growth and development, encompassing aspects like urban expansion [43], land use planning, infrastructure development [44], and population density, contributes to the intricate and inconsistent nature of this relationship [9,45,46]. More detailed explorations of specific dimensions within population growth concerns are essential to understanding how population growth concerns can affect residents' water conservation behaviors.

The negative associations of concerns about water quality and water bills with water conservation behaviors need to be carefully considered in the context of this study. One explanation for the negative association between concerns about water bills and water conservation behaviors is that higher water consumption results in elevated money that the residents have to pay for water, heightening the concerns about water bills. From the information-processing perspective, if residents do not conserve the water, they will receive feedback from the environment: rising water bills. When such information enters the residents' minds, they will be more likely to be concerned about water bills. If the residents still do not know water conservation methods, they might be trapped in a feedback loop that makes them bear the financial costs of wasted water and unable to manage water efficiently. Disseminating knowledge of water conservation methods will be helpful to break this loop. Doing so will help not only alleviate the financial burden induced by water bills but also contribute to more effective water management at the local level.

As for the negative association between concerns about water quality and water conservation behaviors, it suggests that individuals concerned about the safety of their drinking water might exhibit less motivation to adopt water-saving measures, possibly perceiving these concerns as barriers to conservation efforts, as noted by Lyach and Remr [47], Tanellari*, et al.* [48] and Mumbi and Watanabe [49]. However, further studies are needed for more insights and detailed explanations.

The study's findings show the potential of establishing an eco-surplus culture (e.g., water conservation habit) by letting the residents recognize the existing local issues associated with the environment (e.g., water shortage/drought). The recognition can stimulate a collective sense of responsibility for environmental sustainability and foster eco-consciousness and responsible resource management practices [50], which is pivotal for not only water conservation promotion but also the sustainable development of the community. Suppose the eco-surplus mindset is successfully built among community residents. In that case, it will aid in transforming water-related behaviors and promote behaviors that contribute to creating surplus value for the environment, such as watershed restoration, tree planting, and community-driven environmental initiatives [51]. This approach can help foster more sustainable and harmonious interactions between humans and the environment. Thus, policymakers in Albuquerque and other areas with similar geographical and climatic features are recommended to craft policies and programs that broaden the reach of information through various channels to disseminate water conservation methods and enhance residents' awareness of environmental problems in the local areas [52-54]. This might make water-saving alternatives feasible, empower individuals to transform from an eco-deficit mindset to an eco-surplus one, and develop an increased sense of responsibility [22-24,55].

The current study has specific limitations that are outlined here to ensure transparency [56]. The reliance on self-reported willingness and the sample size limited to Albuquerque pose challenges in generalizing findings to diverse geographical and climate contexts in the United States. Future research should be conducted to investigate the impacts of water scarcity concerns and climate change beliefs in varied settings.

Despite identifying a positive link between the concern about population growth and water conservation behavior, the link's weak reliability calls for further exploration. Examining the multidimensional nature of the population growth concern and potential mediating factors is essential for a comprehensive understanding. In future research, qualitative methods, such as interviews or focus groups, could explore people's diverse attitudes toward population growth and development, shedding light on the factors influencing the association with water conservation behavior.

Future research should validate the eco-surplus culture concept across diverse cultural and geographical settings to enhance its external validity. Longitudinal studies are recommended to understand the evolving dynamics between concerns about local issues and water conservation behaviors over time. Additionally, integrating eco-surplus culture with established behavioral theories and exploring its global applicability in regions with distinct water challenges will contribute to a more comprehensive understanding of its impact on sustainable water management practices worldwide.

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