Multidimensional Water Knowledge Index (WKI) Assessing the Public Understanding of Water Challenges in Lebanon

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Abstract

This study aims to develop and validate a multidimensional Water Knowledge Index (WKI) to assess public scientific literacy regarding water-related challenges, focusing on Lebanon's unique water issues. The WKI evaluates knowledge across seven domains: Basic Water Literacy (BWL), Water Management Knowledge (WMK), Water Pollution and Quality (WPQ), Water Technology Awareness (WTA), Climate Change Impact (CCI), Policy and Legal Knowledge (PLK), and Cultural and Social Impact (CSI). Data were collected through surveys administered to 384 participants across Lebanese governorates. Principal Component Analysis (PCA) and Factor Analysis were applied to assign domain weights and validate the index.

The national average WKI score was 5.10, with disparities among governorates. Baalbek-El Hermel scored highest (5.43) due to strong WMK and CSI, while Beqaa scored lowest (4.60) due to deficiencies in WTA and PLK. PCA identified WMK, CSI, and BWL as the most significant contributors to water literacy. Domain-specific trends revealed strengths in WMK and WPQ but significant gaps in WTA and CCI across all regions.

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The WKI provides a comprehensive framework for assessing water knowledge, revealing critical gaps in technology and climate awareness. These findings underscore the need for targeted educational programs and policy interventions to enhance public understanding of water management, particularly in regions like Beqaa. Expanding the WKI application and incorporating behavioral insights could improve its utility in addressing Lebanon's water challenges and fostering sustainable practices.

Keywords: Water Knowledge Index (WKI), Water Management Knowledge (WMK), Lebanon, Principal Component Analysis (PCA), Water Technology Awareness (WTA).

1. Introduction

Water is a fundamental resource that is essential for life and ecosystem functioning. Yet, the world faces increasingly severe water-related challenges such as water scarcity, pollution, and the impacts of climate change, which threaten both human populations and environmental sustainability (UNESCO, 2020; Gleick & Cooley, Freshwater scarcity, 2021). Addressing these issues requires technological solutions and a well-informed public equipped with the scientific knowledge necessary to engage in water management and conservation efforts (Safriel, et al., 2005). The scientific literacy of individuals regarding water issues—including knowledge of the water cycle, pollution control, and sustainable water use—plays a critical role in shaping effective water policies and promoting behaviors that can mitigate the ongoing water crisis.

In this context, developing an index quantifying people's scientific knowledge about water challenges is crucial for assessing current knowledge levels and guiding future educational and policy initiatives, especially in a country like Lebanon, which faces significant water-related challenges due to over-extraction of groundwater, pollution of water resources, and the impacts of climate change. Lebanon's complex hydrological landscape, rapid urbanization, and inadequate water infrastructure underscore the urgent need for increased public awareness and scientific knowledge regarding water management.

An effective Water Knowledge Index (WKI) must cover a broad range of topics—such as water literacy, water management, pollution awareness, climate change impacts, and technology—and use a robust, data-driven methodology to ensure accuracy and relevance. Principal Component Analysis (PCA) and Factor Analysis are widely recognized as powerful tools for reducing the dimensionality of data and extracting key factors that explain the variance in survey responses, making them ideal for constructing such an index (Jollife, 2002; Field, 2018). These methods allow for the weighting of different components of water knowledge based on empirical data, ensuring that the index reflects the relative importance of each aspect of water literacy. By applying these statistical techniques, this study seeks to create a comprehensive, flexible index that provides valuable insights into public understanding of water-related issues, thereby assisting educators, policymakers, and researchers.

The growing global water crisis underscores the importance of scientific knowledge about water challenges is highlighted by the ever-increasing global water crisis. Water scarcity affects billions of people worldwide, with the World Health Organization (WHO) estimating that by 2025, half of the world's population will be living in water-stressed areas (WHO, 2023). Furthermore, the impacts of water pollution, inefficient water management, and climate change exacerbate the existing strain on water resources, particularly in developing regions (Safriel, et al., 2005). Public awareness and scientific literacy about these issues are critical for enabling communities to engage with water policies and conservation practices effectively (Monroe, Plate, Oxarart, Bowers, & Chaves, 2019). However, the challenge remains to accurately measure and assess public knowledge of water issues comprehensively and meaningfully. Current methods, such as simple quizzes or surveys, often fail to capture the full complexity of water-related scientific understanding (Khalid, 2001).

Numerous studies have focused on the relationship between scientific literacy and water management. For example, Gleick et al. (2021) emphasized the need for a scientifically informed public to address the global water crisis, arguing that public awareness and education are as important as technological innovations in securing sustainable water use. Safriel et al. (2005) highlighted the importance of public knowledge in water governance, particularly in developing regions where poor water management can exacerbate environmental degradation and social conflict. Furthermore, Monroe et al. (2019) demonstrated that environmental education, specifically in water conservation, directly impacts individual and community behavior, encouraging sustainable water use and management practices.

Efforts to measure water literacy have resulted in the development of various localized indices. For instance, Dean et al. (2016) developed a community water knowledge index to assess water literacy and its variations across different population segments in Australia, while Evans and Boyer (2015) developed a climate resilience index for water resource management in regions vulnerable to climate change, helping assess local knowledge and preparedness. However, these indices are often limited in scope, geographical reach, or their use of simple statistical methods for analysis. There is a clear need for an index that comprehensively assesses scientific knowledge of water issues across multiple domains and employs advanced statistical techniques like PCA and Factor Analysis to ensure accurate weighting of the different knowledge components.

The key issue lies in measuring scientific knowledge about water challenges in a way that reflects the complexity and multidimensional nature of the subject. Existing tools are often too narrow, failing to capture the breadth of water-related issues or to account for the unequal importance of different knowledge domains (e.g., water management, pollution, climate impacts). This raises several key questions:

- How can we systematically measure individuals' scientific knowledge about water challenges across diverse populations and contexts?
- What are the most critical knowledge domains that should be included in such an index?
- How can we ensure that the index accurately reflects the relative importance of different water-related knowledge areas?

The main challenge is to develop an index that not only evaluates public knowledge comprehensively but also prioritizes different domains based on their real-world importance.

This study hypothesizes that a multidimensional WKI, weighted using PCA and Factor Analysis, can effectively quantify the scientific knowledge of individuals regarding water challenges. Furthermore, we hypothesize that Different domains of water knowledge (e.g., water management, pollution, climate change impacts) contribute unequally to overall water literacy. Moreover, PCA and Factor Analysis can provide an objective, data-driven method to derive appropriate weights for each knowledge domain, thereby improving the precision and utility of the index.

The primary goal of this study is to develop and validate a WKI that measures and understands the public's level of scientific knowledge about water issues in the context of global water challenges. Accordingly, this can be considered essential for designing effective educational and policy interventions that can mitigate these challenges.

2. Study area

Lebanon is a small country located in the eastern Mediterranean, with an area of approximately 10 452 square kilometers (figure 1). This country is geographically diverse, featuring coastal plains, mountain ranges, and inland valleys (FAO, 2008). This diverse topography contributes to its complex hydrological systems, including rivers, aquifers, and springs that provide water to both urban and rural populations. Despite its rich water resources, Lebanon has been experiencing significant water-related challenges that have escalated in recent decades.

Despite its rich water resources, this study is conducted in a country facing serious water challenges due to a combination of natural and human-induced factors. Lebanon's water resources are primarily threatened by the over-extraction of groundwater, particularly in regions such as the Bekaa Valley, where agriculture is heavily dependent on these water resources (UNDP, 2014). Groundwater, which is essential for Lebanon's water supply, is being depleted at an unsustainable rate due to excessive pumping for agriculture and increasing reliance on private wells amid unreliable public water systems (Comair, McKinney, & Maidment, 2013). Additionally, pollution is a major concern, with water sources contaminated by untreated sewage, industrial waste, and agricultural runoff, severely affecting water quality (El-Fadel, Zeinati, & Jamali, 2017). The pollution of Lebanon's rivers, such as the Litani River, which is vital for irrigation and domestic use, exemplifies the gravity of the water pollution issue (Houri & El Jeblawi, 2007).

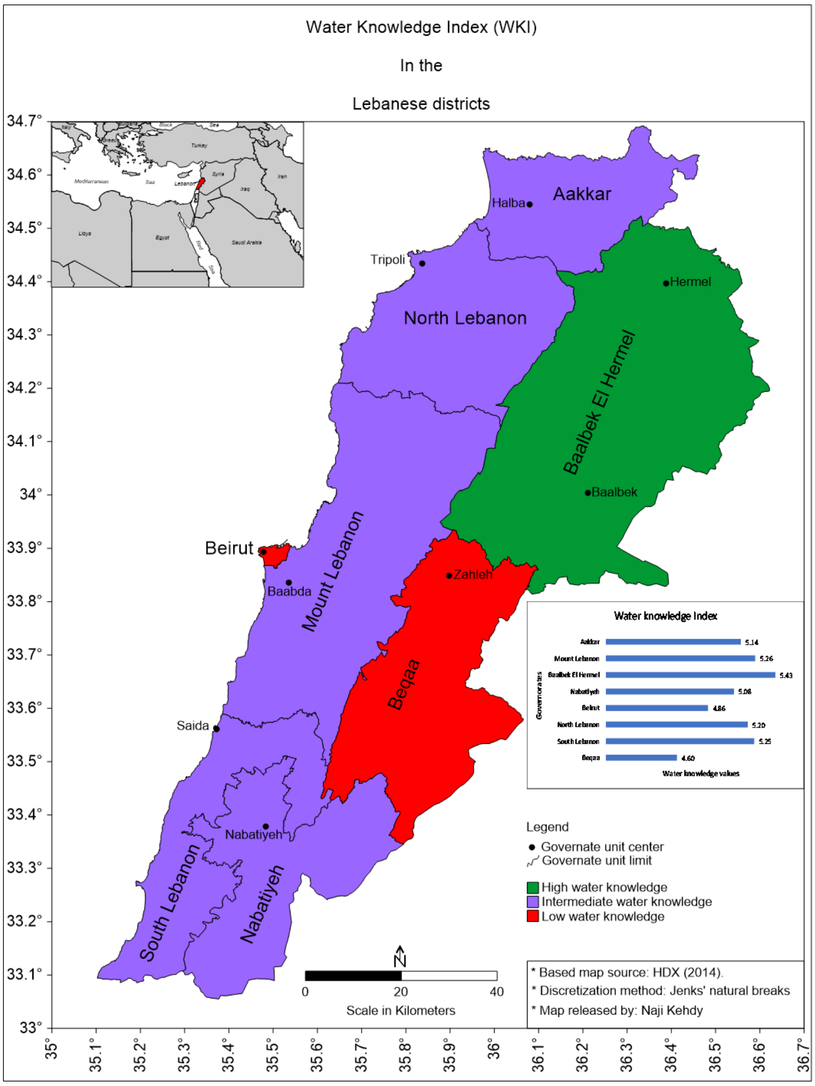


Figure 1: Study area

Climate change further exacerbates these challenges by altering precipitation patterns, leading to irregular rainfall, prolonged droughts, and diminished snowpacks, which are essential for recharging Lebanon's rivers and aquifers (ESCWA, 2017). With climate change projections indicating increased temperatures and decreased annual rainfall, Lebanon's water resources will face growing strain, highlighting the need for effective management and conservation strategies (Verner, 2012). Moreover, urbanization and rapid population growth, particularly with the influx of refugees in recent years, have placed further pressure on Lebanon's already fragile water infrastructure. Beirut and other urban centers have seen substantial increases in water demand, but the water supply network is outdated and suffers from high levels of water loss due to leakage. In rural areas, particularly in the Beqaa Valley and the south, water infrastructure is inadequate to meet growing demands, leading to widespread reliance on private water trucking and unauthorized water connections (World Bank, Lebanon Water Supply Augmentation Project: Environmental and Social Impact Assessment, 2018).

Given these multifaceted challenges, there is an urgent need for increased public awareness and scientific knowledge regarding water management in Lebanon. A better-informed public can play a critical role in supporting sustainable water practices, participating in policy advocacy, and ensuring the responsible use of water resources (El-Fadel, Zeinati, & Jamali, 2017).

3. Methods and tools

The methodology for constructing the WKI includes several key stages: survey design, data collection, and the application of statistical techniques such as PCA and Factor Analysis to assign weights and validate the index. Below is a detailed description of each step in the methodology.

3.1. Conceptual Framework for the Water Knowledge Index

The WKI is structured to evaluate knowledge across multiple domains critical to understanding water issues. These domains are:

- Basic Water Literacy (BWL): Knowledge of the water cycle, sources of freshwater, and water distribution.
- Water Management Knowledge (WMK): Understanding of water conservation techniques, agricultural irrigation, and urban water systems.
- Water Pollution and Quality (WPQ): Awareness of the causes of water pollution and knowledge of water treatment methods.
- Water Technology Awareness (WTA): Familiarity with technological solutions for monitoring and purifying water.
- Climate Change Impact (CCI): Knowledge of how climate change affects water resources.
- Policy and Legal Knowledge (PLK): Awareness of national and international water governance frameworks.
- Cultural and Social Impact (CSI): Understanding of the societal and cultural implications of water scarcity.

These domains were identified based on a review of the literature on water literacy and environmental education (Gleick, et al., 2018; Brown & Lall, 2006; Monroe, Plate, Oxarart, Bowers, & Chaves, 2019; IPCC, 2019; Rogers & Hall, 2003; Gilpin, 2014; Sara, 2019). These diverse domains ensure that the WKI captures the multifaceted nature of water-related knowledge.

3.2. Survey Design and Data Collection

A structured survey (Annex 1) was designed to gather data from participants in the study area. Multiple questions represent each domain, and each question is scored on a 0-5 scale, with 0 indicating no knowledge or an incorrect answer and 5 indicating expert-level knowledge or an entirely correct answer. The number of questions per domain varies, ensuring comprehensive coverage of the subject matter.

Table 1: Proportional distribution of survey participants in the Lebanese Governorates

Governorate	Total inhabitants	Percentage	Number of surveys /384
Aakkar	389899	7	28
Baalbek El Hermel	416427	8	30
Beirut	432645	8	31
Beqaa	536718	10	38
Mount Lebanon	1831533	34	131
Nabatiyeh	386077	7	28
North Lebanon	782436	15	56
South Lebanon	578195	11	41
Total	5353930	100	384

Before deployment, the survey was validated through expert review to ensure clarity and relevance to the intended knowledge domains. Once finalized, the survey was administered to a representative sample of 384 participants ((Krejcie & Morgan, 1970) distributed proportionally in the governorates of Lebanon; each governorate had several surveys based on its number of Lebanese residents relative to the total Lebanese citizens (table 1), which counts around 5,353,930 million people (World Bank, 2023). Data collection methods included in-person interviews and online surveys, depending on participant accessibility and the logistics of the study.

3.3. Principal Component Analysis (PCA) for Weighting

After the survey data was collected, PCA was applied to determine the relative importance of each domain within the WKI. This statistical method is used to reduce the dimensionality of a dataset by identifying the components that explain the most variance in the data (Jollife, 2002). In this study, PCA was used to identify which domains of water knowledge contribute the most to overall water literacy and to assign weights to each domain based on the proportion of variance each component explains in the dataset.

In performing PCA for the WKI, 3 structured steps were undertaken to ensure that the final index accurately reflected the most significant domains of water knowledge.

The first step was performing the Covariance Matrix Calculation. This matrix helped to identify the relationships between scores in different domains by analyzing their correlations. By examining these correlations, we could discern which domains shared similar patterns in participant responses and which domains were more independent, providing a clearer picture of how different aspects of water knowledge were interrelated.

The second step involved the Eigenvalue Decomposition of the covariance matrix. Through this process, eigenvalues were derived, representing the amount of variance each principal component accounted for within the data. Higher eigenvalues indicated that a component explained a larger proportion of the variance, highlighting which dimensions were most informative for understanding variations in water knowledge.

Finally, weight assignment was carried out based on the principal components. To assign weights to variables in PCA, the Total Variance Explained table is used to determine how much variance each component explains, providing a weight for each component (Abdi & Williams, 2010). The Component Matrix or Rotated Component Matrix indicates the loadings of variables on each component, with higher loadings signifying stronger contributions (Wold, Esbensen, & Geladi, 1987). Variable weights are calculated by multiplying a variable's loading on a component by the component's weight (based on the variance explained), ensuring that variables are proportionally represented in the final analysis (Rencher & Christensen, 2012). If a variable loads on multiple components, its contributions across components are summed to derive its total weight (Tabachnick & Fidel, 2013). This approach is crucial for accurately constructing indices or models, as it accounts for the relative importance of each variable in the dataset.

3.4. Factor Analysis for Validation

To ensure the robustness of the index, Factor Analysis was conducted using SPSS to confirm the structure of the WKI and to validate the assignment of domains. Factor Analysis helps identify latent variables (factors) that underpin the observed data, ensuring that the selected knowledge domains are distinct and relevant (Field, 2018).

The procedure included the Factor Loadings Calculation which were computed to assess the correlation between each survey question and its underlying domain. Higher loadings indicated stronger relationships between the questions and their respective domains. In addition, the Model Fit

Evaluation used to evaluate the overall fit of the factor model to ensure that the survey responses could be reliably grouped into the pre-defined knowledge domains (BWL, WMK, WPQ, etc.).

Factor Analysis provided additional confidence that the domains used in the WKI accurately reflected different aspects of water-related knowledge and confirmed the weights assigned by PCA.

3.5. Final Calculation of the Water Knowledge Index

The Water Knowledge Index for each participant was calculated by combining the scores for each domain with the corresponding weights derived from PCA. The formula used to calculate the WKI is:

$$WKI_i = \sum_{j=1}^{n} S_{ij} \,.\, W_j$$

Where:

- WKI_i is the Water Knowledge Index for participant *i*,
- S_{ij} is the score of participants *i* in domain *j*,
- W_j is the weight assigned to domain j (derived from PCA),
- n is the total number of domains.

In this formula, the score for each domain S_{ij} is multiplied by the corresponding weight W_j, and the weighted scores are summed across all domains to calculate the final index for each participant.

3.6. Interpretation of the Water Knowledge Index

The final WKI score for each participant represents their overall scientific knowledge of water issues: Higher scores indicate a stronger understanding of water-related challenges, while lower scores suggest knowledge gaps that may need to be addressed through targeted educational interventions or policy measures.

The WKI allows for a detailed analysis of participants' knowledge across various water-related domains and provides a framework for assessing public awareness of water issues. This information can guide the development of educational programs, policy reforms, and awareness campaigns aimed at improving water management and sustainability in Lebanon (Gleick & Cooley, Freshwater scarcity, 2021; Monroe, Plate, Oxarart, Bowers, & Chaves, 2019).

4. Results

The results indicate that the average WKI across all governorates in Lebanon is approximately 5.10, highlighting the need to improve awareness and knowledge to effectively tackle these issues

The index results highlight varying levels of knowledge across participants, pinpointing areas where understanding is stronger, such as basic water literacy and pollution awareness, and identifying gaps, particularly in areas like water technology and climate change (figure 1). This analysis informs potential targeted educational programs and policy development initiatives to enhance Lebanon's capacity for sustainable water management and resilience.

4.1. Analysis of Principal Component Results and Domain Contributions

By employing PCA, the WKI identifies the most significant domains of water knowledge and assigns proportional weights to each domain based on their contributions to overall variance.

Table 2: Total variance explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.555	22.213	22.213	1.555	22.213	22.213	1.432	20.462	20.462
2	1.245	17.789	40.002	1.245	17.789	40.002	1.320	18.856	39.319
3	1.104	15.767	55.769	1.104	15.767	55.769	1.138	16.261	55.579
4	1.060	15.149	70.918	1.060	15.149	70.918	1.074	15.338	70.918
5	.841	12.007	82.925						
6	.665	9.498	92.423						
7	.530	7.577	100.000						
Extraction Method: Principal Component Analysis.									

First, the Total Variance Explained (table 2) provides an overview of the variance contributed by each principal component in the PCA process. Before rotation, the Initial Eigenvalues and Extraction Sums of Squared Loadings indicate that the first four components explain a cumulative 70.918% of the total variance, a substantial portion of the dataset's variability. Component 1 explains the most variance (22.213%), followed by Component 2 (17.789%), Component 3 (15.767%), and Component 4 (15.149%). These values highlight the significance of these four components in summarizing the dataset without excessive loss of information. After rotation, the variance is redistributed for better interpretability.

The adjusted values in the Rotation Sums of Squared Loadings show a more even distribution, with Component 1 explaining 20.462%, Component 2 contributing 18.856%, Component 3 accounting for 16.261%, and Component 4 explaining 15.338%. This even distribution reduces the dominance of the first component and emphasizes the contribution of other components, interpreting results more balanced and insightful.

Table 3: Rotated Component Matrix[a]

	Component			
	1	2	3	4
CSI	.834	.048	-.143	.169
WMK	.748	.063	.119	-.313
WPQ	-.034	.841	.095	.016
PLK	.129	.777	-.160	-.025
WTA	-.230	-.031	.801	-.209
BWL	.320	-.042	.653	.345
CCI	-.064	.000	-.011	.885

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]
a. Rotation converged in 7 iterations.

Table 4: Weight of each knowledge domain

Variable	Original Weight (Decimal)
CSI	0.2291
WMK	0.2323
WPQ	0.1835
PLK	0.2027
WTA	0.2152
BWL	0.2325
CCI	0.1506

Subsequently, the Rotated Component Matrix (Table 3) highlights the loadings of each domain on the principal components after rotation, reflecting the contribution of each variable to the respective components. The domain CSI (Critical Systemic Insight) shows a strong loading on Component 1 (0.834), indicating its significant role in explaining the variance captured by this component. Similarly, WMK (Water Management Knowledge) also loads heavily on Component 1 (0.748), suggesting that these two domains are closely aligned and contribute strongly to systemic understanding of water issues. On the other hand, WPQ (Water Pollution Questions) and PLK (Policy Literacy Knowledge) load strongly on Component 2, with values of 0.841 and 0.777, respectively. This suggests that these domains are closely related and together explain much of the variance captured by the second component. Component 3 is dominated by WTA (Water Technical Awareness) and BWL (Basic Water Literacy), with loadings of 0.801 and 0.653, respectively. These results highlight the shared contribution of technical awareness and basic literacy to this component. Finally, CCI (Climate Change Impacts) loads almost exclusively on Component 4 (0.885), reflecting its distinct and independent role in explaining the variance captured by this component. The rotated matrix effectively aligns each domain with specific components, simplifying the interpretation of their contributions.

At this stage, the Weight (Table 4) provides the normalized weights for each domain based on the PCA results, highlighting the relative importance of each domain in contributing to the overall Water Knowledge Index. The domains CSI, WMK, and BWL are assigned the highest normalized weights, approximately 0.16 (16%), reflecting their critical roles in water literacy.

These weights underline the importance of systemic insights, water management knowledge, and basic literacy in understanding Lebanon's water challenges. Intermediate weights, ranging from 0.13 to 0.15 (13% to 15%), are assigned to WPQ, PLK, and WTA, indicating their moderate contributions. These domains emphasize the importance of pollution awareness, policy literacy, and technical understanding. Finally, CCI has the smallest normalized weight, 0.10 (10%), suggesting that while it plays a distinct role, its contribution to overall water knowledge is less central than the other domains. This weighting provides a clear framework for prioritizing efforts to enhance water knowledge in Lebanon.

4.2. Water Knowledge Index applied in the Lebanese governates

Examining figure 1 reveals notable disparities in water knowledge levels among different Lebanese governorates. These disparities are reflected in the WKI scores, which range from 4.60 in Beqaa, the lowest, to 5.43 in Baalbek-El Hermel, the highest.

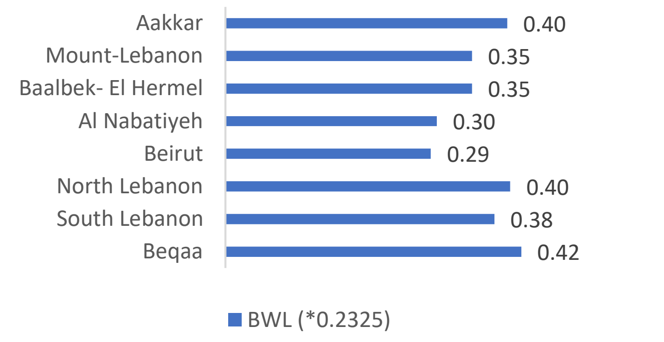
Beqaa's low WKI score is primarily caused by deficiencies in Water Technology Awareness (WTA) and Policy and Legal Knowledge (PLK), with scores of 0.19 and 0.16. The region's dependence on traditional agricultural practices and limited access to technological resources stem from the region's lack of awareness about modern water-saving technologies and limited understanding of water governance frameworks. Consequently, these gaps result in inefficiencies in water use, contributing to Beqaa's struggles with groundwater over-extraction and pollution from agricultural runoff. Furthermore, the low Basic Water Literacy (BWL) score (0.42) exacerbates these issues, as insufficient foundational knowledge makes it difficult for residents to adopt sustainable water practices.

Baalbek-El Hermel's strong WKI score is driven by high contributions from Water Management Knowledge (WMK) (2.79) and Critical Systemic Insight (CSI) (1.23). These strengths are likely caused by the region's reliance on water resources for agriculture, fostering a deeper engagement with water governance and systemic issues. However, the relatively low score in Climate Change Impact (CCI) (0.24) reflects limited awareness of environmental changes, which may stem from insufficient exposure to climate education. As a result, while the region excels in resource management, its residents may struggle to adapt to shifting rainfall patterns and reduced water availability, which are critical for sustaining agricultural productivity in the long term.

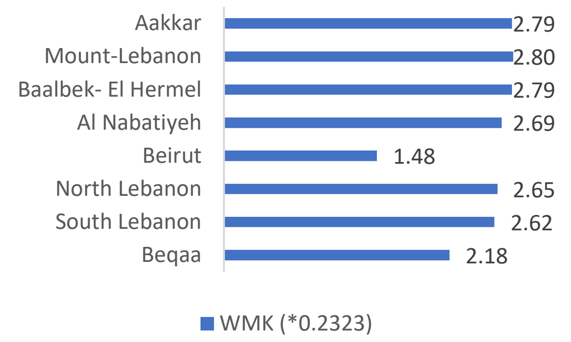
Meanwhile, Beirut’s below-average WKI score reflects the complex interplay between urbanization and water knowledge. The city performs well in WTA (0.89) and CCI (0.76), likely caused by better access to information and exposure to global environmental issues. Nevertheless, low scores in WMK (1.48) and CSI (0.69) suggest a disconnect between urban residents and broader water governance frameworks. This disconnect arises from reliance on centralized municipal water systems, which shield urban populations from direct interaction with natural water sources. Consequently, residents may lack an understanding of systemic water issues, leading to challenges in engaging with policy and governance efforts for sustainable water management.

In addition, Mount Lebanon (5.26) and South Lebanon (5.25), along with Aakkar (5.14) and North Lebanon (5.20), represent regions with moderate WKI scores, close to or slightly above the national average (5.10). These scores are driven by strong contributions in WMK and CSI. Mount Lebanon and South Lebanon achieved WMK scores of 2.80 and 2.62, respectively, while Aakkar and North Lebanon scored 2.79 and 2.65 in the same domain. Similarly, CSI contributions range from 1.02 (Mount Lebanon) to 1.11 (North Lebanon), indicating a solid understanding of systemic water issues across these regions. These strengths are largely caused by the region's mixed urban and rural dynamics, where communities engage with both agricultural and municipal water management practices, fostering awareness of governance frameworks and systemic connections.

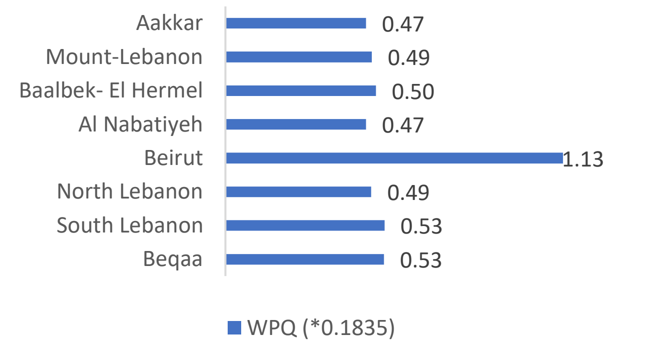
However, moderate scores in BWL and WTA highlight knowledge gaps across these governorates. For instance, BWL scores range from 0.35 (Mount Lebanon) to 0.40 (Aakkar), while WTA scores are particularly low, with values of 0.17 (Mount Lebanon) and 0.15 (Aakkar). These deficiencies are caused by insufficient integration of foundational and technological education into public programs, compounded by limited exposure to advanced water-saving technologies. Moreover, the low scores in CCI, particularly in Aakkar (0.17) and North Lebanon (0.25), further emphasize the lack of climate-related awareness in these regions, likely due to the absence of targeted climate education initiatives. As a result, while the relatively high WMK and CSI scores indicate that these regions are equipped with a basic understanding of water resource management and systemic water challenges, the lower scores in WTA and CCI suggest that residents are unprepared to adopt technological solutions or adapt to the effects of climate change. Therefore, to improve water literacy in these governorates, educational programs should focus on foundational water knowledge, climate change awareness, and the promotion of water-saving technologies. By targeting these gaps, policymakers can enhance the overall water knowledge in these regions, building on their existing strengths in systemic and governance-related domains (figure 2).



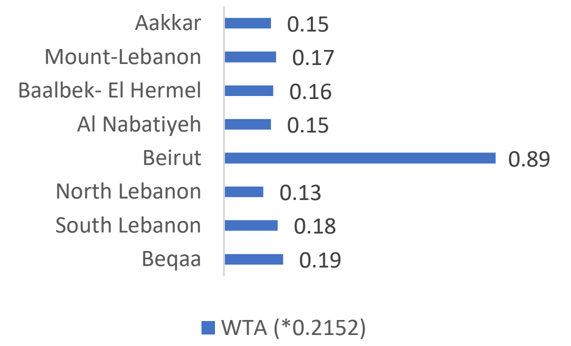
a: BWL domain variations across Lebanese Governorates



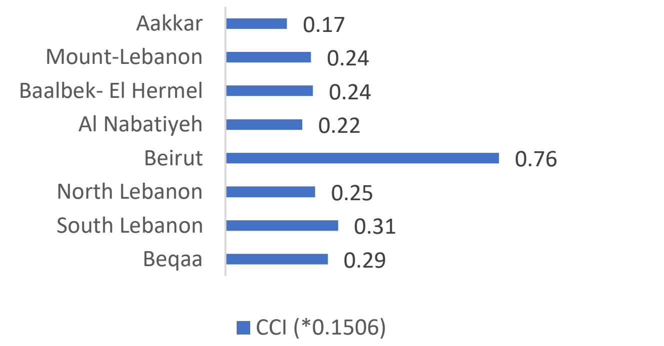
b: WMK domain variations across Lebanese Governorates



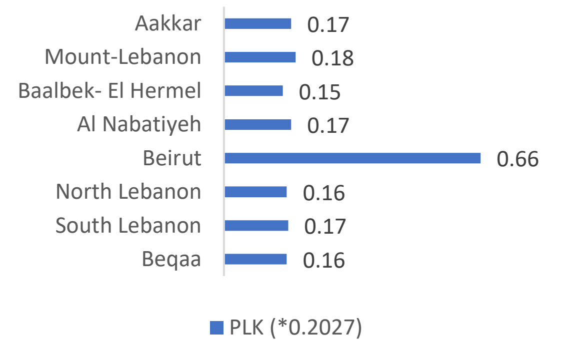
c: WPK domain variations across Lebanese Governorates



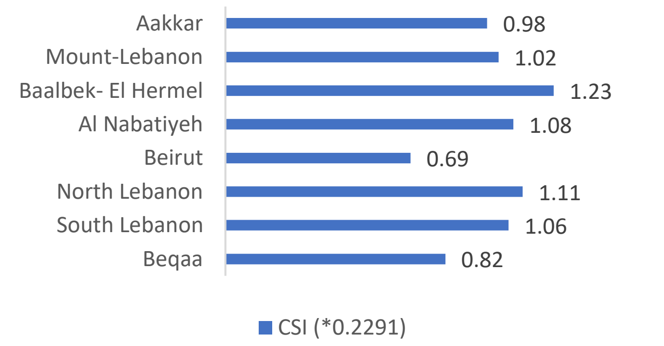
d: WTA domain variations across Lebanese Governorates



e: CCI domain variations across Lebanese Governorates



f: PLK domain variations across Lebanese Governorates



g: CSI domain variations across Lebanese Governorates

Figure 2: Variations in the domain of the WKI across Lebanese governorates

Furthermore, WMK emerges as the most consistent contributor to WKI scores, with high contributions in all governorates, such as 2.80 in Mount Lebanon and 2.79 in Aakkar. This consistency reflects the importance of water governance and management practices in addressing Lebanon's water challenges. The strong performance in this domain is caused by the widespread reliance on water resources for both agriculture and municipal needs, which fosters a baseline understanding of management strategies. However, this also reveals disparities between regions with effective governance systems and those without, resulting in uneven application of these practices (figure 2).

Additionally, BWL and Water Pollution Questions (WPQ) show moderate but stable contributions across most governorates, indicating a foundational understanding of water-related issues among the population. For example, WPQ scores range from 0.47 in Aakkar to 1.13 in Beirut, reflecting varying levels of awareness about water pollution and its impact on public health and ecosystems. These moderate scores are caused by basic educational initiatives that introduce residents to water systems, pollution, and quality. Nevertheless, the results also indicate uneven performance, particularly in regions like Beqaa, where low BWL and WPQ scores hinder the ability to adopt sustainable water practices (figure 2).

In contrast, CCI and WTA consistently show low scores across most governorates, emphasizing critical gaps in public knowledge. CCI scores range from 0.17 in Aakkar to 0.76 in Beirut, reflecting a lack of widespread understanding of how climate change affects water availability and resource management. Similarly, WTA scores remain low, with 0.15 in Aakkar and 0.89 in Beirut, suggesting limited awareness of modern technologies, such as water-saving devices and sensor-based monitoring systems. These deficiencies are caused by the absence of targeted educational programs on climate and technology and result in a population unprepared to adapt to environmental changes or adopt innovative solutions for water conservation (figure 2).

Finally, PLK scores remain low across all governorates, with the highest contribution being 0.18 in Mount Lebanon. This indicates limited public awareness of water-related legal frameworks and governance policies, likely caused by a lack of community engagement in policymaking processes. As a result, residents have minimal participation in advocating for sustainable practices or influencing water policy, reducing the effectiveness of governance efforts. These domain-specific trends underscore the multifaceted nature of water knowledge in Lebanon. While foundational and governance-related domains, such as WMK and WPQ, perform relatively well, the consistently low scores in WTA, CCI, and PLK highlight significant knowledge gaps that must be addressed through targeted education, public awareness campaigns, and policy engagement. These findings emphasize the need for comprehensive strategies to improve water literacy across all domains, ensuring a more water-conscious and resilient society in Lebanon (Figure 2).

5. Discussion

The application of the WKI in this study provided significant insights into the public's understanding of water-related challenges across Lebanese governorates. The multidimensional approach of the WKI, encompassing key domains such as Basic Water Literacy (BWL), Water Management Knowledge (WMK), and Water Pollution and Quality (WPQ), allowed for a comprehensive evaluation of scientific literacy. The results revealed notable strengths in domains like WPQ and BWL, where participants performed moderately well across most regions, such as Beirut (1.13 in WPQ) and Baalbek-El Hermel (0.50 in WPQ). These strengths align with Lebanon's ongoing struggles with water pollution, particularly in the Litani River and other water bodies impacted by industrial and agricultural pollutants. The public's awareness in these areas could be attributed to the visible severity of these crises and the media coverage surrounding them, highlighting their importance in the public consciousness.

However, significant gaps were observed in WTA and Climate Change Impact (CCI) across all governorates, with scores as low as 0.15 in Aakkar (WTA) and 0.17 in Aakkar (CCI). These domains, while critically important for addressing Lebanon's growing water challenges, showed low levels of public understanding. The limited exposure to advanced water-saving technologies and insufficient discourse on climate change impacts appear to be major contributing factors. For example, although Beirut performed relatively well in WTA (0.89) and CCI (0.76) compared to other regions, the overall knowledge levels in these domains remain inadequate. This lack of awareness could impede Lebanon's ability to adopt innovative water conservation practices and develop adaptation strategies essential for addressing climate-induced shifts in water availability, particularly as the country faces altered precipitation patterns and declining freshwater resources.

A notable strength of this study lies in the use of PCA to determine the weight of each domain in the WKI. For instance, WMK and CSI, which were assigned the highest weights, consistently contributed the most to the WKI scores across all regions, underscoring their importance in shaping water knowledge. The data-driven nature of PCA ensured that the WKI was statistically robust, allowing for an objective and reliable assessment of knowledge distribution. Furthermore, the multidimensional structure of the WKI distinguishes this study from prior research, which often focuses narrowly on single aspects of water literacy, such as pollution or basic water availability. By integrating diverse domains, this index provides a comprehensive framework for evaluating water knowledge.

Despite its valuable contributions, the study has notable limitations that warrant consideration when interpreting the results. Firstly, the sample size was limited to 10 participants across governorates, which constrains the generalizability of the findings. While the results offer preliminary insights into regional trends, a larger and more diverse sample would be necessary to draw broader conclusions about water knowledge in Lebanon. For example, the strong performance of Baalbek-El Hermel (WKI: 5.43) and the weaker performance of Beqaa (WKI: 4.60) may reflect regional disparities that could shift with more comprehensive data.

Secondly, while the survey effectively covered a wide range of water-related topics, the depth of questions within certain domains, such as WTA and CCI, was limited. This limitation likely contributed to the low scores in these areas, as more detailed questioning might have better captured participants' understanding of advanced water technologies and the complex interactions between climate change and water systems. Future studies could benefit from incorporating more nuanced questions to address these gaps.

Furthermore, the geographical focus on Lebanon introduces a context-specific limitation. Lebanon’s unique water challenges, including political instability, outdated infrastructure, and reliance on agricultural water use, mean that these findings may not be directly applicable to regions with different water management systems or climate conditions. For instance, the high WMK scores (2.80 in Mount Lebanon and 2.79 in Aakkar) highlight strengths in resource management that may not be relevant in urbanized or industrialized regions elsewhere.

Finally, the temporal relevance of the findings is an important consideration. As water-related challenges evolve due to environmental changes, technological advancements, or policy shifts, public knowledge levels are likely to change over time. For example, the current low CCI scores (0.17 in Aakkar and 0.24 in Baalbek-El Hermel) could improve with increased awareness driven by future climate campaigns. To capture these dynamic changes, longitudinal studies tracking knowledge trends over time would provide more comprehensive insights and ensure that the WKI remains relevant in addressing Lebanon’s water challenges.

Ultimately, while the WKI results highlight valuable insights into Lebanon’s water knowledge landscape, they also underscore critical gaps, particularly in technology and climate awareness. Addressing these deficiencies through targeted education, public awareness campaigns, and policy engagement is essential to fostering a more informed and resilient population capable of managing the country’s pressing water challenges.

6. Conclusion

The development and application of the WKI in Lebanon mark a significant step forward in assessing public knowledge about water-related challenges. The comprehensive structure of the WKI, which integrates multiple domains such as Basic Water Literacy (BWL), Water Management Knowledge (WMK), and Water Technology Awareness (WTA), alongside Climate Change Impact (CCI) and other critical areas, provides a holistic evaluation of water literacy across Lebanese governorates. The use of Principal Component Analysis (PCA) for weighting ensured a statistically robust and empirically grounded approach, allowing for a nuanced understanding of regional disparities in water knowledge.

The results from the case study revealed both strengths and gaps in public knowledge. For instance, strong performance in WMK and Water Pollution Questions (WPQ), with scores such as 2.80 in Mount Lebanon (WMK) and 1.13 in Beirut (WPQ), highlights solid awareness of foundational and pollution-related issues. This reflects the public’s familiarity with pressing challenges such as water quality degradation, particularly in heavily polluted areas like the Litani River. However, the results also exposed critical deficiencies in WTA, as seen in Aakkar (0.15) and Beqaa (0.19), and in CCI, with scores as low as 0.17 in Aakkar. These gaps underscore the urgent need for targeted education in advanced water technologies and climate-related water management.

This study introduces several strong and novel contributions to the field of water knowledge evaluation. The PCA-weighted WKI is a key innovation, offering a reliable method for understanding water literacy at both the individual and regional levels. For example, regions such as Baalbek-El Hermel (5.43) demonstrated how robust management knowledge and systemic insight can elevate overall water knowledge. Conversely, Beqaa (4.60) highlighted the consequences of deficiencies in foundational and technological knowledge, leading to inefficient water resource use.

Additionally, the study’s multidimensional perspective, which incorporates domains like technology, policy, and climate change, expands traditional approaches to water education. This approach acknowledges the complex interplay of factors influencing water management, as reflected in the strong WMK scores across most regions but consistently low scores in PLK (Policy and Legal Knowledge), which peaked at just 0.18 in Mount Lebanon. By including these interconnected factors, the WKI provides a more comprehensive framework for addressing water challenges.

The findings also emphasize the critical need for advanced water technology education, as regions with low WTA scores, such as Beqaa and Aakkar, risk falling behind in their ability to adopt innovative solutions to water challenges. This knowledge gap could hinder the country's overall resilience and adaptability to issues such as water scarcity and inefficient irrigation practices.

Addressing these deficiencies through public education and policy-focused initiatives could enhance community preparedness for future challenges.

The study's results pave the way for promising future research directions. Expanding the sample size to include participants from diverse socio-economic backgrounds, rural and urban settings, and varying educational levels is crucial. This would provide a more granular understanding of how water knowledge varies across Lebanon. Furthermore, conducting longitudinal studies to track how environmental changes, technological advancements, and policy shifts influence water knowledge over time would add depth to the analysis. For example, monitoring how public awareness of CCI evolves as climate impacts become more pronounced could help tailor education programs to address these gaps effectively.

Cross-regional comparisons also hold significant potential. Applying the WKI in other countries or regions with unique water challenges could uncover how context-specific factors like governance and infrastructure shape water knowledge. For example, comparisons with regions that excel in WTA could provide insights into effective strategies for technology integration in Lebanon. Additionally, future research could explore how knowledge translates into behavior, assessing whether increased awareness in domains like WPQ leads to tangible actions such as pollution reduction or support for sustainable policies.

In conclusion, the results of the WKI application in Lebanon underline the strengths of the index in capturing multidimensional water knowledge while also revealing critical areas for improvement. By addressing gaps in technology and climate knowledge, enhancing the depth of public education, and exploring behavioral insights, the WKI can serve as a powerful tool for shaping effective water policies and fostering a more water-literate society in Lebanon.

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Annex 1

1. Basic Water Literacy (BWL)

- **Q1:** What percentage of the Earth's water is freshwater?
  - (a) 10%
  - (b) 3%
  - (c) 20%
  - (d) 5%
- **Q2:** What is the primary source of drinking water for most communities?
  - (a) Rivers
  - (b) Desalination plants
  - (c) Groundwater
  - (d) Oceans
- **Q3:** Which part of the water cycle involves the process of evaporation?
  - (a) Water flowing in rivers
  - (b) Water turning into vapor
  - (c) Water freezing in glaciers
  - (d) Rainfall

2. Water Management Knowledge (WMK)

- **Q4:** What is the most common method used in agriculture to conserve water?
  - (a) Sprinkler irrigation

- (b) Drip irrigation
- (c) Flood irrigation
- (d) Rainwater harvesting

- **Q5:** What is the primary purpose of a water catchment system?
  - (a) To store water for agricultural use
  - (b) To prevent flooding
  - (c) To recharge groundwater
  - (d) All of the above

3. Water Pollution and Quality (WPQ)

- **Q6:** Which of the following is a major source of water pollution?
  - (a) Industrial waste
  - (b) Solar panels
  - (c) Natural springs
  - (d) Rainwater
- **Q7:** What does "eutrophication" refer to in the context of water pollution?
  - (a) Depletion of oxygen in water bodies
  - (b) Increased salt levels in water
  - (c) Excessive nutrients in water leading to algae growth
  - (d) Sedimentation

4. Water Technology Awareness (WTA)

- **Q8:** Which technology is commonly used to monitor water quality?
  - (a) BMP sensors
  - (b) Photovoltaic cells
  - (c) Turbidity sensors
  - (d) Barometers
- **Q9:** What is reverse osmosis used for in water treatment?
  - (a) Removing bacteria from water
  - (b) Filtering out large particles
  - (c) Desalinating seawater
  - (d) Treating wastewater for agriculture

5. Climate Change Impact (CCI)

- **Q10:** How does climate change most directly affect water resources?
  - (a) By increasing oxygen levels in oceans
  - (b) By changing rainfall patterns and intensifying droughts
  - (c) By increasing the salinity of freshwater lakes
  - (d) By preventing evaporation

6. Policy and Legal Knowledge (PLK)

- **Q11:** Which international agreement primarily addresses transboundary water management?
  - (a) Paris Agreement
  - (b) Ramsar Convention
  - (c) Helsinki Rules
  - (d) Kyoto Protocol
- **Q12:** Which body is typically responsible for regulating water quality in most countries?
  - (a) Ministry of Agriculture
  - (b) Ministry of Environment
  - (c) World Health Organization
  - (d) Local municipalities

7. Cultural and Social Impact (CSI)

- **Q13:** How does water scarcity most impact local communities in developing countries?
  - (a) By reducing tourism
  - (b) By limiting industrial growth
  - (c) By forcing people to migrate and leading to social conflict
  - (d) By increasing opportunities for investment in agriculture
- **Q14:** Why is it important to include community members in water management decisions?
  - (a) To ensure that policies reflect local needs
  - (b) To reduce government expenses
  - (c) To create jobs in the community
  - (d) To promote private sector investment