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From Drought to Diagnosis: Basin-Level Water Scarcity and Public Health Risks in Türkiye within the Framework of Sustainable Development Goals (SDGs)

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ABSTRACT

The objective of this study is to investigate intensifying water stress in Türkiye. It aims to quantify basin-level water stress, analyze supply-demand trends, and interpret the resulting public-health implications using an ecological time-series analysis. The research is underpinned by concepts from environmental health and epidemiology. It links hydrological stress, defined by the supply–demand gap (surface-water storage vs. municipal demand), to direct and indirect public-health outcomes, including hygiene, food safety, and healthcare delivery. This nationwide ecological time-series analysis integrated reservoir-fullness data (2010–2023) with per-capita municipal wastewater data (2014–2022) across 17 hydrological basins. Linear trends (2014–2022) and a quartile-based Water Stress Score were computed to classify 2022 stress. Projections for 2030–2035 were based on linear trend extrapolation of the 2014–2022 dataset. The results revealed declining supply (e.g., Great Menderes, -2.23 pp/year) and rising demand (e.g., Antalya, +9.05 m³/person/year) in most basins. The 2022 ranking placed Antalya, Marmara, and Great Menderes as high-risk. Projections suggest further deterioration. These findings are discussed in the context of mounting public-health risks, including water-borne infections, sanitation overload, infant methemoglobinemia, and food insecurity. The practical implications call for integrated early-warning systems, enhanced water-safety measures in health facilities, and basin-specific demand-management reforms to sustain public-health resilience. This study provides an updated, nationwide quantitative analysis of water stress at the hydrological basin level. Its value lies in integrating disparate national datasets to create a predictive stress score and directly link hydrological trends to specific, emergent public-health vulnerabilities in Türkiye.

1. INTRODUCTION

Water is a critical environmental determinant for sustaining life and maintaining ecosystem balance [1]. Globally, fluctuating supply, rising demand, and infrastructure pressures are amplifying water security risks in Türkiye as well. Decreasing precipitation, rapid urbanization, and agricultural demand jointly impose substantial stress on water resources [2-4].

Türkiye is classified among countries experiencing "water stress" based on per-capita annually available water. With population growth, per-capita availability is projected to approach scarcity thresholds reported in the literature by 2030 [5]. This trajectory may impose additional burdens on infectious disease risks, hygiene, and continuity of health services [6].

This study aims to integrate basin-level water supply (reservoir fullness) and demand (per-capita wastewater) data for Türkiye, to quantify the 2014–2022 trends, generate a 2022 water-stress positioning map, and present health-related risk projections for 2030 and 2035.

2. THEORETICAL FRAMEWORK

This study is theoretically positioned at the intersection of environmental epidemiology and the Sustainable Development Goals (SDGs) framework. The core analytical model adopts an eco-epidemiological approach, conceptualizing water scarcity as a critical environmental determinant of public health [1].

Specifically, the framework links failures in SDG 6 (Clean

Water and Sanitation)-quantified in this study as a widening supply-demand gap-directly to subsequent risks for SDG 3 (Good Health and Well-being). The "supply" component (reservoir fullness) represents the availability of safe water [7], while the "demand" component (per-capita wastewater) acts as a proxy for the strain on municipal sanitation infrastructure [8].

Our framework posits that as this gap widens, two primary risk mechanisms are amplified: (1) direct exposure to microbiological and chemical contaminants in deteriorating water sources, and (2) systemic failure of public health infrastructure. This model allows for the identification of geographically specific public health vulnerabilities, including direct infectious disease risks [9, 10], sanitation-related failures [11], and disruptions to essential healthcare services like sterilization and dialysis [12].

Furthermore, the framework extends to indirect health impacts, connecting water scarcity to SDG 2 (Zero Hunger) through threats to food security in key agricultural basins and to SDG 11 (Sustainable Cities and Communities) by analyzing environmental degradation, such as particulate pollution [13]. By integrating these domains, this study provides a quantitative model to assess Türkiye's progress toward these interconnected SDGs, framing water security as a foundational pillar of public health.

3. METHODS

A mixed-method research design integrating quantitative and qualitative data was employed to analyze basin-based water scarcity risk in Türkiye. The analytical process included data preparation, merging, trend analysis, and scenario evaluation. All quantitative analyses were performed in a Google Colaboratory environment using the Python programming language (version 3.12.12) and core data science libraries (Pandas, Matplotlib, and Seaborn).

3.1 Data sources and preprocessing

The study dataset was compiled from three main sources:

Water Supply Data: Published by the General Directorate of State Hydraulic Works (SHW), this dataset includes the annual average reservoir fullness (%) of Türkiye's 17 major basins for the years 2010–2023 [7].

Water Demand Data: Obtained from the Turkish Statistical Institute (TSI), this dataset presents annual per-capita wastewater volumes (m^3/year) by province, covering the 2014–2022 period [8].

During preprocessing, quantitative datasets from SHW and TSI were standardized. Missing or erroneous entries were corrected, column names were harmonized, and data types were converted for analytical compatibility.

3.2 Data integration and construction of the analytical dataset

A multi-step integration process was implemented to merge supply and demand data derived from distinct administrative and geographic units:

Basin Assignment Strategy: Since municipal wastewater data is reported at the provincial level by TSI, a "Dominant Basin" approach was adopted for spatial allocation. Although provincial administrative boundaries often overlap with multiple hydrological basins, municipal wastewater infrastructure is typically centralized and discharges into the primary river system associated with the city center. Therefore, each province was assigned to the single hydrological basin that contains its population center and primary discharge points. For instance, while the administrative territory of Ankara province spans multiple basins, its wastewater data was assigned to the Sakarya Basin, which receives the load from the metropolitan area. This infrastructure-based assignment aligns with the operational reality of urban water management, prioritizing the location of pollutant generation over geometric surface area.

Basin Mapping: Provincial wastewater demand data were geographically matched to their corresponding water basins. For instance, data from the "Ankara" province were assigned to the "Sakarya Basin."

Restructuring Data Format: Both datasets were converted from wide to long format to enable time-series analysis.

Data Merging: The processed supply and demand datasets were merged using "Basin" and "Year" as key variables, yielding a final analytical dataset containing both reservoir fullness and per-capita wastewater for each basin and year.

3.3 Analytical approach and visualization

Four major analytical approaches were applied to the final dataset:

Time-Series and Trend Analysis: Line graphs were created to examine temporal changes in supply and demand indicators for each basin during 2014–2022. To determine the statistical reliability of the observed trends, the significance of the linear regression slopes was tested. A p-value of less than 0.05 ($p < 0.05$) was considered statistically significant, confirming that the temporal changes in supply and demand were not due to random variation.

Net Change Analysis: Differences in supply and demand indicators between 2014 and 2022 were calculated and presented as ranked bar charts highlighting basins with the greatest positive and negative changes.

Water Stress Ranking Model: A composite stress index (0 = minimum risk, 1 = maximum risk) was calculated using normalized supply and demand data. Basins were classified into quartile-based categories - Low, Medium, High, and Very High Risk. A quartile-based Water Stress Score was computed to classify stress levels.

3.4 Construction of the Water Scarcity Index

To quantitatively assess and rank the water stress levels of the basins, a composite Water Scarcity Index (WSI) was developed based on the interaction between water supply (reservoir occupancy) and water demand (per capita wastewater discharge). The index construction involved three steps: normalization, formulation, and sensitivity analysis.

3.4.1 Data normalization (scaling)

Since the supply indicator (percentage, %) and demand indicator (volume, m^3/year) possess different units and scales, direct comparison was not feasible. To resolve this, the Min-Max normalization technique was applied to rescale both indicators into a dimensionless range of [0, 1]. The formula used is:

$$X(norm,i) = (Xi - Xmin) / (Xmax - Xmin)$$

where, *Xi* is the raw value for basin i, and *Xmin* and *Xmax* are the minimum and maximum values across all basins for the given year, respectively.

3.4.2 Index formula and weighting

The composite index was formulated based on the logic that higher demand increases water stress, whereas higher supply (occupancy) mitigates water stress. Therefore, the normalized supply component was inverted (1 − Snorm). The Weighted Sum Model (WSM) was employed to calculate the final score:

$$WSIi = wd \times D(norm,i) + ws \times (1 - S(norm,i))$$

where,

WSIi: Water Scarcity Index score for basin i (Range: 0 to 1; higher score indicates higher risk).

Dnorm: Normalized demand value (Wastewater per capita).

Snorm: Normalized supply value (Dam occupancy rate).

wd and *ws*: Weights assigned to demand and supply, respectively (where wd + ws = 1).

In the baseline analysis, an equal weighting approach (wd = 0.5, ws = 0.5) was adopted. This rationale assumes that hydrologic availability (supply) and consumption pressure (demand) contribute equally to the overall water security of a basin.

3.4.3 Sensitivity analysis

To address potential uncertainties regarding the choice of weights and to ensure the robustness of the basin rankings, a sensitivity analysis was conducted. We tested the stability of the index under three distinct weighting scenarios:

1). Supply-Dominated Scenario: (ws = 0.8, wd = 0.2) – Prioritizes physical water availability.

2). Balanced Scenario: (ws = 0.5, wd = 0.5) – The baseline assumption.

3). Demand-Dominated Scenario: (ws = 0.2, wd = 0.8) – Prioritizes consumption habits and pressure.

3.5 Ethics and data availability

This study is based on secondary datasets that are publicly available and contain no human participant data or personally identifiable information (SHW reservoir levels, TSI environmental indicators, and TSMS rainfall reports). Under institutional practices and national regulations, studies of this nature do not require ethics committee approval; therefore, no application was submitted. Participant consent is not applicable.

Data availability: Data from SHW, TSI, and TSMS were obtained from their publicly accessible web portals (access dates are provided in the references). Processed datasets and analytical scripts are available from the corresponding author upon reasonable request.

4. RESULTS AND DISCUSSION

This section presents the key findings derived from the analysis of supply (reservoir fullness) and demand (per-capita wastewater) data for Türkiye’s 17 major water basins. The results reveal current basin-level water stress conditions, decadal trends, and future projections.

4.1 Water supply trends (reservoir fullness)

Examining the 2014–2022 period shows a marked downward trend in reservoir fullness across most Turkish basins. Analysis of annual change rates indicates the steepest supply declines in:

- Great Menderes Basin (average −2.23 per year)
- Gediz Basin (average −2.00 per year)
- Western Black Sea Basin (average −1.97 per year)
- Lake Van Basin (average −1.94 per year)

Conversely, a modest increasing trend in supply was identified in a limited number of basins such as the Konya Closed Basin (+ 0.59), Marmara Basin (+ 0.27), and Eastern Black Sea Basin (+ 0.22%).

In terms of supply stability, there are notable differences among basins. Marmara (standard deviation: 16.36), Susurluk (15.69), and Gediz (13.88) exhibit the highest variability in reservoir fullness, whereas the Eastern Black Sea Basin (1.78) has the most stable supply.

Basin-level year-to-year changes and linear trend lines are shown in Figure 1.

4.2 Water demand trends (per-capita wastewater)

During the period examined, annual per-capita wastewater- a proxy for water demand-increased across most basins, indicating inefficient use of water and growing pressure on municipal infrastructure. The basins with the highest increases were:

- Antalya Basin (average + 9.05 m^3/person per year)
- Eastern Black Sea Basin (average + 6.05 m^3/person per year)
- Yeşilırmak (average + 5.65 m^3/person per year)

However, in some basins experiencing the most critical supply issues, demand decreased. Notably, the Great Menderes (−8.8 m^3/person), Lake Van (−2.85 m^3/person), and Gediz (−2.55 m^3/person) basins showed declines; yet these reductions are far from compensating for the observed supply decreases.

Basin-level per-capita wastewater time series and linear trend lines are presented in Figure 2.

4.3 Statistical significance of trends

To validate the observed temporal patterns, a linear regression analysis was conducted for each basin. The statistical significance of the trends was evaluated using p-values, where a value of $p < 0.05$ indicates a statistically significant change. The regression coefficients (slopes) and risk classifications based on trend directions are summarized in Table 1.

The analysis confirms that the decline in water supply is statistically significant in several critical basins. Specifically, the Great Menderes ($p = 0.004$), Gediz ($p = 0.016$), Western Black Sea ($p < 0.001$), Aras ($p = 0.001$), and Sakarya ($p = 0.049$) basins exhibit significant negative slopes in reservoir levels, confirming that the drying trend is structural rather than a transient fluctuation. The Van Lake basin shows the steepest statistically significant decline in supply (Slope: −2.273, $p < 0.001$).

On the demand side, the Antalya Basin stands out with a massive annual increase in per-capita wastewater (Slope: + 17.5), which is statistically significant ($p = 0.027$). Similarly, the Aras Basin shows a significant increasing trend in demand (p = 0.043). Interestingly, while the Euphrates–Tigris basin is classified as “High Risk” in terms of trend direction, its demand increase approaches statistical significance (p = 0.086).

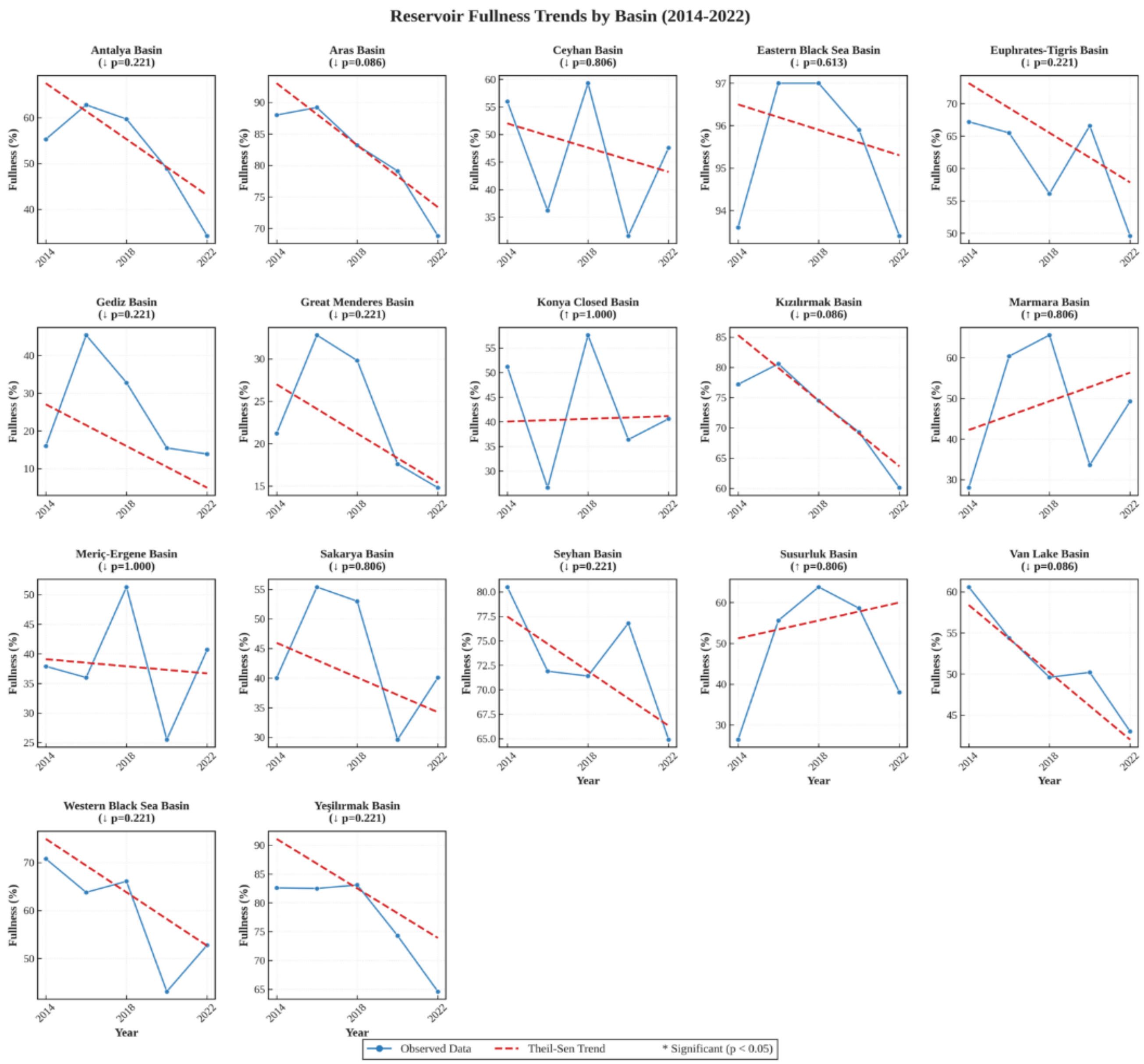

Figure 1. Reservoir fullness by basin, 2014–2022, with linear trend (dashed)
Note: Y-axis represents percentage (%). Data derived from General Directorate of State Hydraulic Works [7]

Table 1. Statistical analysis of water supply and demand trends by basin (2014–2022)

Basin	Slope (Supply)	P-Value (Supply)	Slope (Demand)	P-Value (Demand)	Trend Risk Class
Antalya Basin	-1.092	0.054	17.500	**0.027***	High Risk
Aras Basin	-1.300	**0.001***	9.750	**0.043***	High Risk
Ceyhan Basin	-0.825	0.443	1.250	1.000	High Risk
Eastern Black Sea Basin	0.186	0.348	4.750	0.462	Medium Risk
Euphrates-Tigris Basin	-1.250	**0.021***	5.467	0.086	High Risk
Gediz Basin	-2.069	**0.016***	-4.458	0.221	Medium Risk
Great Menderes Basin	-1.900	**0.004***	-16.792	**0.027***	Medium Risk
Konya Closed Basin	0.500	0.584	4.458	0.806	Medium Risk
Kızılırmak Basin	-1.550	**0.010***	0.625	1.000	Medium Risk
Marmara Basin	0.236	0.913	7.250	0.462	Medium Risk
Meriç-Ergene Basin	-0.809	0.324	8.583	0.221	High Risk
Sakarya Basin	-1.200	**0.049***	0.625	0.806	Medium Risk
Seyhan Basin	-0.900	0.101	5.250	0.130	High Risk
Susurluk Basin	-0.790	0.324	10.500	0.221	High Risk
Van Lake Basin	-2.273	**< 0.001***	-9.500	0.221	Medium Risk
Western Black Sea Basin	-1.720	**< 0.001***	-5.625	0.312	Medium Risk
Yeşilırmak Basin	-0.367	0.443	11.417	0.086	Medium Risk

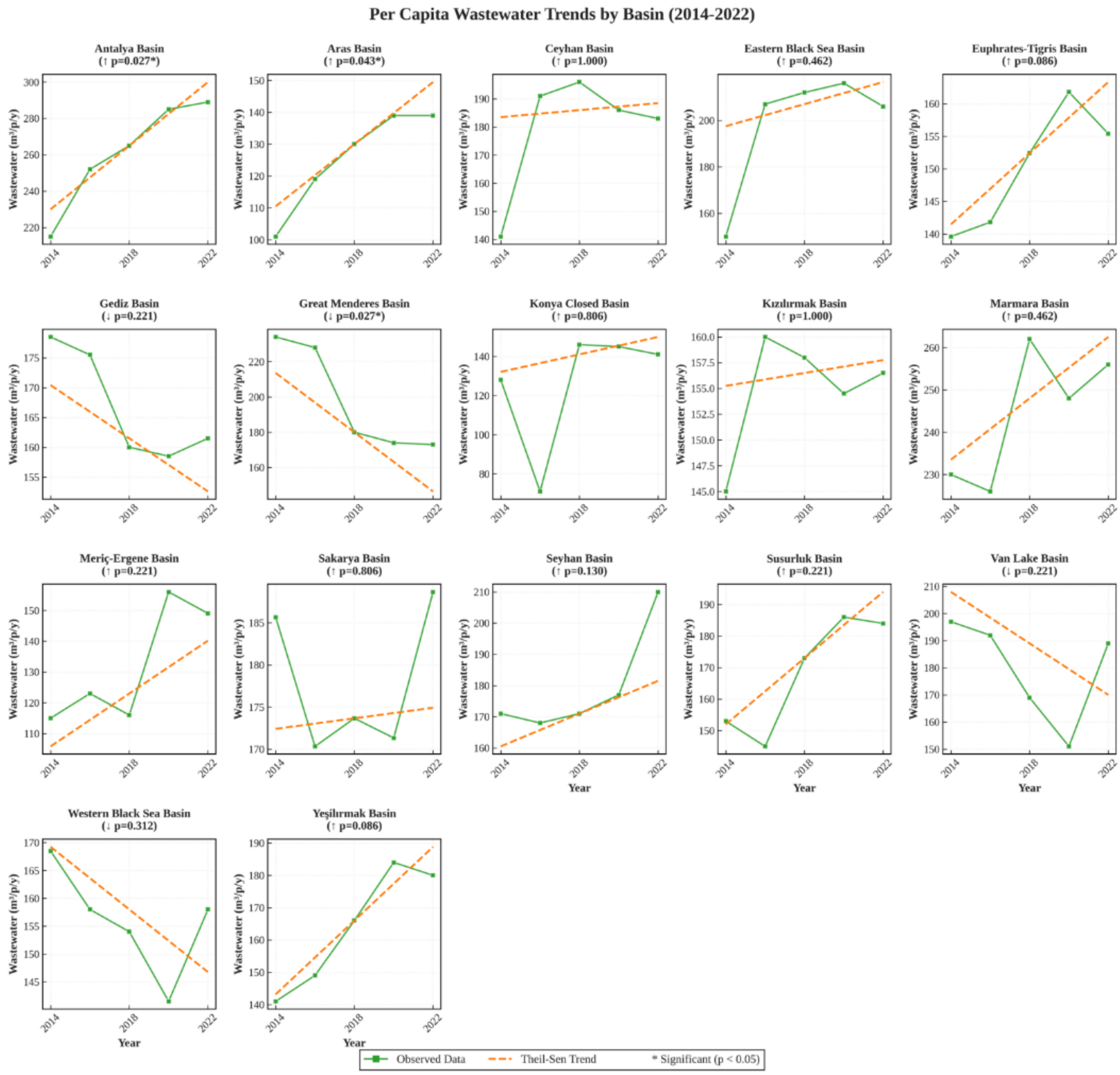

Figure 2. Per-capita wastewater by basin, 2014–2022, with linear trend (dashed)

Note: Y-axis represents cubic meters per person per year (m³/person/year). Data derived from Turkish Statistical Institute [8]

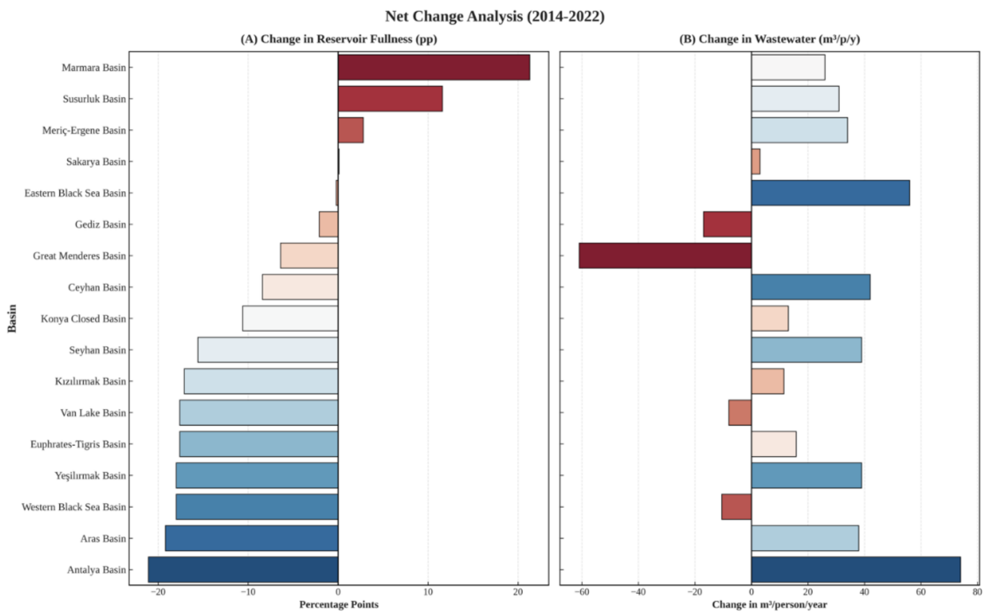

Figure 3. Basin-level net change between 2014 and 2022: (A) change in reservoir fullness (percentage points), (B) change in per-capita wastewater (m³/person/year)

Note: Panel (A) units are percentage points (pp); Panel (B) units are m³/person/year. Calculated by authors based on SHW and TSI datasets

Basins such as Antalya, Aras, Ceyhan, Euphrates–Tigris, Meriç–Ergene, Seyhan, and Susurluk were classified as "High Risk" in the trend analysis because they exhibit the most dangerous combination: a negative slope for supply (decreasing availability) and/or a positive slope for demand (increasing pressure).

4.4 Supply–demand imbalance and risk projection

The analyses indicate a deepening critical imbalance between decreasing supply and increasing demand nationwide. During 2014–2022, reservoir fullness declined in most basins while per-capita wastewater increased; key basins are summarized in Figure 3.

According to the final risk projection, basins are classified as follows:

High-Risk Group: Antalya, Euphrates–Tigris (Fırat-Dicle), Meric–Ergene, Seyhan, Susurluk, and Yeşilırmak-generally due to decreasing supply and increasing demand dynamics.

Moderate-Risk Group: Great Menderes, Gediz, Western Black Sea, Lake Van, Sakarya, Kızılırmak, Ceyhan, Eastern Black Sea, Marmara, and Konya Closed.

The comparative ranking of the basins by their composite water-stress scores is presented in Figure 4, summarizing basin-level risk levels from Very High to Low for 2022.

Basins are ranked according to their composite water-stress scores (0 = minimum, 1 = maximum risk).

The figure highlights Antalya, Marmara, and Great Menderes (Büyük Menderes) basins as the most stressed regions, whereas Aras and Eastern Black Sea basins show the lowest risk levels.

Future projections point to further deterioration, especially for basins in the Aegean Region:

The Great Menderes Basin's water supply is projected to fall to critical levels (< 1%) in 2030 and approach complete depletion (virtually 0%) by 2035. Similarly, the Gediz Basin's water supply is expected to decline to near-zero levels by 2035.

The Gediz Basin's water supply is expected to decline to −8.29% in 2035.

These findings indicate that current water resources may become insufficient to meet future demand.

The study findings demonstrate that, at the basin level in Türkiye, decreasing supply and increasing demand are progressing simultaneously, thereby amplifying water-stress risk. This pattern aligns with trends reported in the water security literature and points to near-term risks for public health.

The most fundamental finding of our study is the widening gap between water supply and demand. This situation represents not only a resource deficiency but also a primary mechanism that generates and sustains public health risks. This mechanism exerts a twofold pressure: a declining and deteriorating supply on one side, and a growing, infrastructure-straining demand on the other.

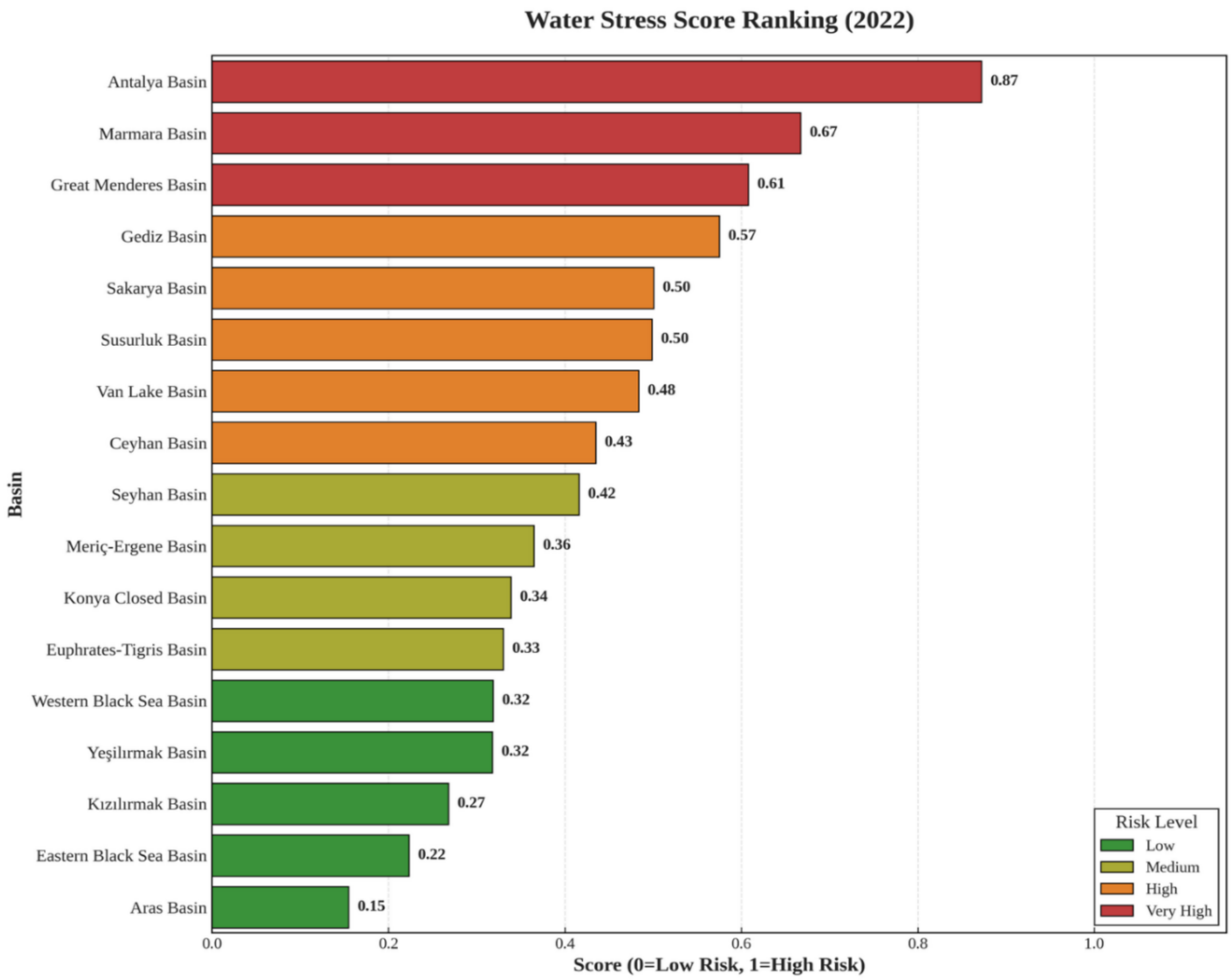

Figure 4. Ranking of water stress score and level by basin (2022)

Note: Scores are normalized between 0 (Lowest Risk) and 1 (Highest Risk) based on quartile distribution of the composite index

Our findings reveal dramatic declines in water supply, particularly in the Great Menderes (-2.23 per year), Gediz (-2.00), and Lake Van (Van Gölü) (-1.94) basins. Decreasing water levels in reservoirs bring two main public health threats. The first is an increase in pollutant concentration. A lower water volume intensifies the existing microbiological and chemical load, creating a favorable environment for waterborne pathogens such as *E. coli, Salmonella spp., Vibrio cholerae, and Shigella spp.,* thereby placing greater stress on water treatment systems [9]. This may also trigger the emergence and spread of infections such as *tularemia (rabbit fever)*, which are transmitted primarily through the consumption of contaminated water [14].

Drought and water withdrawal create stagnant water bodies that provide ideal breeding conditions for mosquitoes carrying diseases such as *West Nile virus* and leishmaniasis [10]. Recent studies on the vector Phlebotomus tobbi indicate that environmental conditions are becoming increasingly favorable for the transmission of Leishmania infantum, suggesting that the risk of autochthonous cases may no longer be theoretical [15].

Simultaneously, the demand increase observed in the Antalya Basin (+ 9.05 m^3/person per year) and Yeşilırmak Basin (+ 5.65 m^3/person per year) is straining the carrying capacity of existing municipal and health infrastructures. The rising volume of wastewater, particularly in areas with insufficient treatment facilities, increases the risk of untreated or inadequately treated sewage being discharged directly into rivers and groundwater sources.

This may lead to nitrate contamination of groundwater, predisposing infants to methemoglobinemia (blue baby syndrome). In addition, rising demand and stagnation in aging systems can facilitate Legionella colonization in domestic hot-water systems, elevating the risk of *Legionnaires' disease* [11]. This contamination cycle also promotes the spread of fecal-orally transmitted diseases such as *hepatitis A and E* [16].

The most dangerous outcomes of this twofold pressure emerge at the intersection of water infrastructure and the healthcare system. Water cuts or drops in network pressure caused by declining levels and rising demand can increase the risk of external contaminant infiltration in regions with old infrastructure.

More importantly, this crisis may disrupt healthcare delivery. Interruptions in facilities where water is critical-such as hospitals, Primary Care Centers, and laboratories bring vital processes like sterilization and dialysis to a halt. Even minor interruptions in hand hygiene are known to increase hospital infection rates [12].

In summary, the supply–demand imbalance revealed by our findings is not merely an environmental issue but also a public health challenge that heightens risks related to infectious diseases and sanitation infrastructure, thereby undermining the resilience of the healthcare system.

Our findings indicate that the water crisis in Türkiye is not homogeneous; rather, each basin exhibits a distinct risk profile. These regional differences cause public health threats to become geographically specialized, highlighting that a "one-size-fits-all" intervention strategy would be inadequate. Instead, region-specific approaches must be developed.

The most alarming results concern projections for the Great Menderes and Gediz basins. The record annual declines in water supply (-2.23 and -2.00) and the projected total depletion of active reservoir storage by 2035 threaten both the agricultural productivity of these regions and Türkiye's overall food security.

Water scarcity reduces agricultural irrigation capacity, decreasing crop yields and increasing the risk of malnutrition and micronutrient deficiencies, particularly among rural and low-income populations. More dangerously, compensatory over-extraction of groundwater may increase arsenic, nitrate, and heavy metal concentrations in irrigation water, allowing these toxins to enter the human food chain [13, 17, 18].

In the Antalya Basin, the combination of agricultural demand and tourism-driven water pressure (+ 9.05 m^3/year) further increases the risk of waterborne and foodborne pathogen transmission. The statistical analysis (Table 1) corroborates these findings, confirming that the rapid depletion in the Great Menderes Basin and the demand surge in Antalya are significant structural shifts ($p < 0.05$) rather than temporary anomalies.

The Konya Closed Basin illustrates the indirect and less visible public health impacts of the water crisis. The slight increase in reservoir fullness (+ 0.59) masks the excessive stress on the region's groundwater reserves, its primary source of water.

Years of over-extraction have not only degraded water quality but also caused soil desiccation, generating a new environmental health threat: dust and particulate pollution. Drought-induced wind erosion has increased concentrations of PM_{10} and $PM_{2.5}$. During summer, drought-induced soil desiccation in the Konya Basin creates conditions conducive to elevated PM_{10} levels, which are hypothesized to potentially exceed air quality thresholds and exacerbate respiratory conditions such as asthma [12].

This demonstrates that water scarcity can trigger not only waterborne diseases but also respiratory health problems through air quality degradation.

The Marmara Basin demonstrates that the impact of supply–demand imbalance on public health is amplified by population density and industrial activity. Water stress in this region is compounded by the heavy burden placed on treatment infrastructure by high population and industrial waste. During drought periods, when water discharge decreases, the dilution capacity of rivers and other water sources declines. Consequently, chemical pollutants from industrial and domestic waste may reach hazardous concentrations. Thus, the principal public health risk in Marmara involves not only microbiological contamination but also long-term chemical exposure and associated chronic diseases, should treatment systems fail to cope.

Projections for 2030 and 2035 indicate that Türkiye is transitioning from temporary drought periods into irreversible water scarcity in several regions. This shift necessitates transforming public health interventions from reactive responses to proactive, long-term planning. The negative supply scenarios projected for the Great Menderes and Gediz basins represent not only an economic problem but also a potential social and mental health crisis.

As agricultural production declines, these areas may experience income loss, rural-to-urban migration, and increasing social stress. Economic uncertainty and future-related anxiety could trigger mental health issues and social maladaptation, particularly among young adult men. Prolonged water restrictions and a generally pessimistic outlook could even heighten "water anxiety", a form of anxiety disorder, leading to social insecurity even in urban populations [19]. Hence, water scarcity must be recognized as a major public health threat.

This chronic scarcity scenario also threatens the resilience of the healthcare system. Findings project that water supply in the Sakarya Basin will drop to 20.4%, and in the Lake Van Basin to 18.84% by 2035. This implies that water outages may cease to be exceptional events and instead become part of daily life. Interruptions in critical services such as sterilization, dialysis, and laboratory operations could become routine.

Therefore, future projections clearly underscore the urgent need for Türkiye to address water security as both a public health and national security issue.

While the United Nations classifies Türkiye as a “water-stressed country,” current data and projections reveal that the nation is rapidly advancing toward a chronic water scarcity regime in several regions [16]. According to the Turkish Basin Water Scarcity Risk Analysis and Projection Report, more than half of the country’s 17 main water basins fall under High or Moderate risk categories.

This represents not merely an environmental or agricultural issue, but an urgent, multidimensional public health threat-encompassing infectious disease, food security, mental health, and the sustainability of the healthcare system.

The report clearly reveals the current fragility of Türkiye’s water balance. Data from 2014–2022 show that water supply-measured as reservoir fullness-has steadily declined across much of the country, while water demand-measured as per-capita wastewater increased. The regions where this dangerous gap widens the most are of particular concern.

According to the final risk analysis, the Aras, Antalya, Euphrates–Tigris (Fırat–Dicle), Meric–Ergene, Seyhan, Susurluk, and Yeşilırmak basins fall into the “High Risk” category. Their common feature is rising demand driven by population growth and agricultural activity despite declining supply. For example, in the Antalya Basin, supply declines by 1.35% per year on average, while per-capita demand increases by 9.05 m^3 per year.

The most dramatic picture, however, appears in the Aegean Region, though classified as “Moderate Risk,”-has the bleakest future projections:

Great Menderes Basin: Experiences a record 2.23% annual decline in supply.

Gediz Basin: Faces an average 2% annual decline in supply.

Given their central role in national agricultural production, these two basins are also strategic for Türkiye’s food security.

The most striking and concerning findings are the projections for 2030 and 2035, which indicate that parts of Türkiye will move beyond episodic drought into a persistent water-deficit regime.

For the Great Menderes Basin, projections suggest that supply will drop to critical scarcity levels in 2030 and face potential hydrological exhaustion by 2035. For Gediz, supply is expected to decline to critically low levels approaching zero by 2035.

For Gediz, supply is expected to decline to −8.29% by 2035.

Other critical areas: In the Sakarya Basin, where industry and population are concentrated, supply is projected to fall to 20.4% by 2035, while in the Antalya Basin—a hub of tourism and agriculture—it is projected to fall to 29.67%.

The public health impacts of water scarcity span a wide spectrum, encompassing both direct and indirect effects:

Infectious Diseases and Hygiene Crisis: Declining water levels increase pollutant concentration in reservoirs and lakes, creating favorable conditions for waterborne pathogens such as *E. coli* and *Salmonella spp*. The growing volume of wastewater places a heavier burden on treatment facilities, raising the risk of partially treated effluent contaminating surface and groundwater sources. Water shortages and pressure drops in networks hinder sterilization and hygiene in critical settings such as hospitals, schools, and food production facilities, heightening the risk of nosocomial infections and outbreaks.

Food Security and Nutrition Challenges: Water shortages in basins like the Great Menderes and Gediz, which are vital for agricultural production, lead directly to reduced crop yields and rising food prices. More critically, the uncontrolled extraction of groundwater to compensate for diminished surface water increases levels of arsenic, nitrate, and heavy metals, allowing these contaminants to enter the human food chain.

Environmental and Indirect Health Effects: In groundwater-dependent regions such as the Konya Closed Basin, excessive water withdrawal may lead to soil desiccation and wind erosion, raising particulate matter (PM_{10}, $PM_{2.5}$) levels that exacerbate asthma and chronic respiratory diseases (COPD).

Psychosocial Impacts and Societal Stress: Drought and water scarcity impose severe economic pressure and future anxiety on rural populations dependent on agriculture and livestock. Income loss, migration trends, social stress, and “water anxiety” represent less visible yet equally critical public health consequences of the water crisis.

This study is ecological in design; therefore, the findings cannot be generalized to the individual level. Province-to-basin matching may be influenced by differences in data resolution and administrative boundaries. Trend and projection analyses are based on linear extrapolation; climate variability, demand shocks, and structural changes may widen confidence intervals.

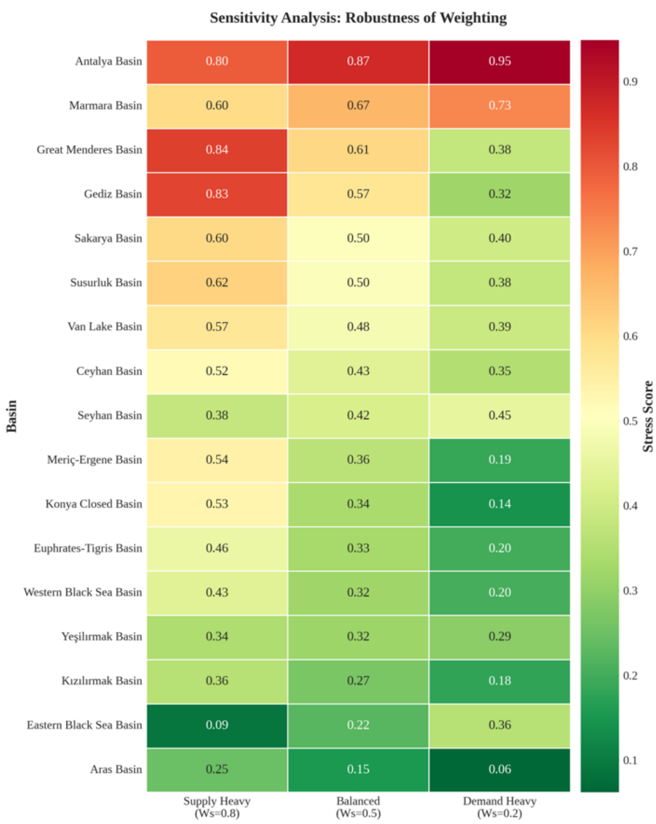

Figure 5. Sensitivity analysis

To validate the reliability of these rankings, we conducted a sensitivity analysis under different weighting scenarios (Figure 5). The results demonstrate that the classification of Antalya and Great Menderes as 'High Risk' basins remains consistent even when the weights for supply or demand are heavily altered. This confirms that the identified water stress is structural and not an artifact of the index construction.

5. CONCLUSION AND POLICY RECOMMENDATIONS

The data and projections indicate that Türkiye urgently requires bold and immediate action to address water scarcity, which has evolved from an environmental or economic issue into a national security and public health crisis.

Our results demonstrate that water stress in Türkiye is not homogeneous. In basins such as Antalya and Gediz, the convergence of tourism and intensive agricultural activities (high demand) with drought conditions (low supply) maximizes risk. Conversely, in basins like Aras and the Eastern Black Sea, relatively regular precipitation regimes and lower population density have maintained these regions in the 'Low Risk' category for the time being. This disparity underscores the importance of adopting basin-specific, customized strategies rather than a uniform national water policy.

Key policy priorities include:

Establishing "Basin-Level Water Emergency Plans", ensuring real-time data integration among the State Hydraulic Works (SHW), Ministry of Health, Ministry of Agriculture, and Turkish Statistical Institute (TSI) to enable proactive risk management.

Mandating backup water storage and treatment capacities for hospitals and primary care centers, and transforming "Water Safety in Health Plans" into a national guideline.

Promoting agricultural transformation by eliminating flood irrigation, encouraging low-water-demand crops and drip irrigation through state incentives.

Implementing nationwide awareness campaigns on water efficiency and conservation, in collaboration with local governments and civil society organizations.

Türkiye's water future depends on actions taken today-otherwise, today's projections will become tomorrow's harsh reality.

Our study introduces a novel composite index that complements the standard SDG 6.4.2 indicator ('Level of water stress'). While SDG 6.4.2 traditionally measures the ratio of total freshwater withdrawal to available resources, our index specifically targets the 'municipal resilience' aspect of water stress. By integrating reservoir fullness with per-capita wastewater generation, our approach captures the immediate operational risks to public health infrastructure as the stability of urban storage and the load on sanitation systems-which broader hydrological metrics may overlook. While global indices like WRI Aqueduct provide a macro-level baseline for physical water risk, our basin-specific analysis offers a more granular assessment of the supply-demand gap that directly influences hygiene-related vulnerabilities and healthcare service continuity. Therefore, this study contextualizes the local implementation of SDG 6 by highlighting how storage depletion and infrastructure overload can jeopardize public health outcomes, even in regions where aggregate theoretical flow might seem sufficient.

Ultimately, ensuring water security in these high-risk basins is not merely an infrastructure challenge, but a prerequisite for Türkiye to achieve the integrated targets of SDG 3 (Good Health) and SDG 6 (Clean Water) by 2030.

6. LIMITATIONS

Furthermore, the allocation of provincial wastewater data to hydrological basins relied on a deterministic mapping based on the province's city center. While this 'dominant basin' approach captures the vast majority of the municipal discharge load, it does not account for peripheral towns or districts that may drain into adjacent basins. A population-weighted spatial apportionment was not feasible due to the lack of disaggregated district-level wastewater datasets. Consequently, demand estimates for geographically expansive provinces may contain minor spatial uncertainties.

Secondly, this study creates a risk model based on environmental exposure (reservoir levels and wastewater load) rather than utilizing direct health outcome data (e.g., hospital admissions for waterborne diseases). While environmental determinants are strong predictors, future studies should validate these risk scores with epidemiological surveillance data.

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