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Climate Change and Water Security in Istanbul: Human Rights Challenges Amidst Urban Growth and Infrastructure Vulnerability

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Abstract

Istanbul, which is a rapidly growing metropolitan municipality, straddling two continents, faces acute water security challenges which are exacerbated by anthropogenic climate change, unchecked urbanization and pronounced socio-economic disparities, thus precipitating significant human rights ramifications. The increased likelihood of droughts, especially evident on the European side where 65% of the population lives while only 35% of water resources are available, is linked to the increased variability of precipitation and the trend of temperatures in response to climate change. Urban settlement in important hydrological catchments has increased the chances of contamination and industrial wastes contribute to further loss in quality of freshwater. Structural weaknesses (as illustrated by the Melen Dam whose impairment has greatly reduced storage capacity) increase the vulnerability of supply systems. Collectively, these stressors undercut equitable access to adequate and potable water, thus violating the fundamental right to water and sanitation. Addressing the water crisis in Istanbul requires a series of complex interventions, such as climate adaptation plans, updating the network of water infrastructure and implementing strong environmental protection measures. The case study shows how this problem is not unique to Istanbul; megacities around the world struggle with similar problems as they strive to balance urban development with climate resilience and human rights. Guaranteeing long term water security in Istanbul is thus not only necessary to ensure the maintenance of public health, safeguarding ecological integrity but also ensuring social equity within the domains of social justice and resource allocation in the face of climatic stressors and infrastructural constraints.

Keywords: Istanbul, Water Security, Climate Change, Urbanization, Human Rights, Freshwater Quality, Social Equity

1. Introduction

Istanbul, a megacity, which is expected to be placed in a strategic location on Eurasian border has witnessed unprecedented urban growth over the last few decades. The Turkish Statistical Institute (2024) states that the current population of the city is over 16 million people, which ranks it among the most populous cities in the world. This rate of growth has put a lot of strain on the natural resources of Istanbul especially the water supply systems. Although the area houses nearly 65 percent of the population of the city, the European part has a significantly lower proportion of water resources, which is why there is a significant spatial imbalance between the resources and

demand (Istanbul Water and Sewerage Administration [ISKI], 2023). The increasing urbanization, industrialization and the increasing per capita consumption of water have further increased the annual demand of water which is estimated to be approximately 3.8billion cubic meters and is expected to be more than 4billion cubic meters by 2030 (ISKI, 2023). The growing needs are intensified by the effects of climate change that have caused the risk to reduce the quantity and quality of water, dramatically increasing the susceptibility of the city to droughts, floods, and ecological destructions (UNEP, 2022). Here, due to the water scarcity problem, effective and timely water security management is required to sustain the socio-economic development of Istanbul.

Climate change has aggravated hydrological uncertainty in the Marmara region, which results in the change in precipitation patterns and the increase in the occurrence of extreme weather events such as sustained droughts, heatwaves, and rainy variability in Istanbul (IPCC, 2023). The Mediterranean climate of Istanbul has already been characterized with longer dry periods and a decline in the amount of precipitation per year by about 1015 per cent compared to the historical standards (Turkish State Meteorological Service, 2024). Surface reservoirs have been greatly affected by the trend; storage had gone down by up to 4,050% in the highest of summer over the last ten years (ISKI, 2023). The rate of groundwater recharge has also decreased posing a significant complementary source. The infrastructure is vulnerable to these climate challenges. As an example, the Melen Dam, which was intended to increase the reliability of water supply, has been functioning at a reduced capacity since 2021 due to technical and other factors that reduced its available storage capacity to over 500 million cubic meters (ISKI, 2024). Uncontrolled urbanization has also favored the development of informal settlements in the vicinity of large watersheds, which would increase the burden of untreated sewage and industrial effluents (Erdogan et al., 2021). The combination of these factors explains why adaptive water-management approaches where a combination of climate-resilience principles and urban planning is adopted are urgently needed.

Accessibility of clean and sufficient water is also a concept that is gradually becoming a key human right, something that a United Nations resolution of 2010 confirmed. However, this ideal is not met in the situation of Istanbul. Informal peripheral settlers have access to water with a restricted number of hours per day, and in many cases, they use polluted water (Freedom from Hunger, 2021). Recent surveys in 2023 indicate that despite approximately 90 per cent of the residents in Istanbul having access to tap water, the proportion is reduced to less than 75 per cent among low-income and informal residents. These inequalities represent a serious issue of public health, which increases the threat of water-related diseases and other chronic illness complications (Kaya and Yilmaz, 2022). The inequities pose a severe social justice challenge, as they tie up the safety of water with the quality of life, the chance of getting a job, and human dignity. This gap needs to be filled not only to clean the environment, but also to maintain social unity and equality in a constantly growing urban environment.

The nature of the water security problem in Istanbul is aggravated by the city management structure. Several organizations, such as ISKI and other municipal authorities are in charge of water services and hence lack coordination and fragmentation in control. Thus, collective lack of information, lack of transparency in decision-making, and a lack of involvement of the concerned communities in general, especially the marginalized ones that are not necessarily involved in the policy-making process, are pronounced (Transparency International Turkey, 2024). The loss of infrastructure due to budgetary cuts and bureaucracy has greatly hampered the ability of the municipality to respond in time to changes in climatic conditions and societal needs. Additionally, environmental laws are not fairly applied and thus pollution on sensitive watersheds continues. This disjointed mosaic of organizations is a barrier to the creation of an integrated and flexible

water governance system that Istanbul desperately needs in order to prosper in the face of climate change pressures.

The complexity of interacting pressures requires the adoption of integrated urban water management measures in accordance with the principles of social justice. The strategies envisage cross-sectoral planning in the areas of water supply, wastewater, stormwater, and land-use planning and thus facilitates efficient use of resources and conservation of ecosystem integrity. The analysis of climate-risks as a part of the design, operation, and regulation of the water infrastructure is an indispensable part of the development of resilience to rising hydrological uncertainty. In addition, it is important that the marginalized communities are incorporated into the participatory governance mechanisms to have equitable access and to enable the local stewardship. The example of Istanbul offers a rather informative lesson to the megacities of the world that face the combined effects of climate change, high rates of urbanisation, and social disparity; these issues should be resolved by means of coherent, open, and dynamic water governance in order to make the urban future sustainable.

2. Literature Review

2.1 Climate Change Effects on Urban Water Systems

Urban water systems are becoming more and more affected by climate change, a phenomenon that is becoming a topic of primary concern in the current environmental and water-resource studies. Research indicates that the change of rain patterns, increase in temperature, and increasing runs of extremes like droughts and heat waves are radically changing the global hydrology (IPCC 2023, UNEP 2022). These changes are particularly dangerous in Mediterranean styles such as those found in Istanbul as even minor changes in the seasonal precipitation may decrease the water supply significantly (Shahid 2011). As a result, the surface-water supply is undermined, and the ground water is recharged less, which causes additional stress to the city water systems (Turkish State Meteorological Service 2024). At the same time, increased temperatures increase evaporation of reservoirs and soils, which increases the scarcity of water (Mirza, 2011). These changes in the environment provide a necessity in the creation of adaptive water-governance frameworks that enable the dynamic decision-making in case of uncertainty. However, existing literature is disproportionately based on the biophysical effects and is relatively silent on the impacts of these climatic challenges being reflected in governance and operational adjustments within an urban environment, thus demonstrating a gap in the literature.

2.2 Effect of the Unauthorized Settlement and the Industrial Pollution on the Quality of Watersheds

The high rate of urbanization, which has been promoted by unplanned and unlawful settlements, has attracted a growing academic interest as a key factor in causing the degradation of watersheds and the worsening of water-quality in cities. Erdogan et al. (2021) note that these informal, often do not have appropriate sanitation facilities and, therefore, the untreated sewage is released into major catchments areas. This kind of runoff significantly worsens aquatic ecosystems by increasing levels of nutrients and pathogen loads, which complicates the processes of water-treatment, and threatens the health of the population. These negative impacts are further enhanced by industrial pollution, which causes the presence of chemical contaminants and toxicants such as heavy metals, hydrocarbons, and toxicants into urban waters (Kaya & Yilmaz, 2022). The proximity of the informal settlements to the industrial areas in the major urban reservoirs enhances the risk of contamination hence the need to stress the interconnection between the land-use patterns, pollution management, and the water-quality management. Regardless of the fact that the topic of informal urbanization and pollution adversely affects the water resources, the literature

is inclined to focus on the discussion of the discussed phenomena without a corresponding institutional and governance analysis. Limited studies have been done to examine the interaction between the socio-environmental factors and the processes of governance, and this represents a critical area that interdisciplinary studies can be undertaken in the future.

2.3 Infrastructure Challenges in Megacities: Aging Dams and Vulnerability of Water Supply Systems

The ageing and low investment of the water infrastructure and the increasing demand are among the challenges facing urban water infrastructure in megacities. The Melen Dam constructed in Istanbul to enhance storage has been constrained in its operation due to a lack of proper maintenance, and this demonstrates how critical infrastructure can be vulnerable to climate change and bad governance (ISKI, 2023). Generally, the city water networks are highly leaky and lose 3040% of the water that should be billed. It is also not always enough to be modernized (ISKI, 2023; Fatima et al., 2021). These issues undermine the capacity of this system to manage droughts and floods and decrease the trustworthiness and equity of water supplies. Even though the technical infrastructure gaps are commonly documented in other studies, a limited number of studies examines the impact of institutional capacity and governance on the upgrades and adaptive management. The research should be more closely integrated in order to study infrastructure resilience and the dynamics of governance in a changing climate.

2.4 Human Rights Perspectives on Water Security and Social Equity in Urban Contexts

It is a generally accepted fact that the right to clean and sufficient water is one of the fundamental human rights (United Nations General Assembly, 2010), and that the urban water security often fails to reach this goal, especially among the disadvantaged groups of people. The articles by Freedom from Hunger (2021) and Kaya and Yilmaz (2022) reveal significant water and sanitation shortages in cities. In the informal settlements, individuals undergo periodic supply and use dysfunctional facilities (Yuan and Sawin, 2024). The absence of these poses a social justice threat and increases the risk of water-borne diseases. According to the researchers, the sustainable urban water management should be based on the rights-based systems, which consider the social equity (Nasir and Akbar, 2024). Although there is a growing agreement, the existing literature on the how urban water policies can operationalize equity and inclusion in relation to vulnerable groups is limited, thus creating a research knowledge gap that is highly critical, particularly in the context of inclusive governance amid the growing climate stress.

2.5 Governance and Institutional Capacity Gaps in Managing Integrated Water and Climate Risks

Inadequacies in governance and institutional capability significantly hinder the effectiveness of integrated water and climate risks management in Istanbul, a fast-paced urbanizing megacity environment which has been characterized by severe water security limitations. This fractured government infrastructure, which is characterized by the lack of synchronization of the municipal and regional authorities, derails the capacity of the city to address climate-related changes in precipitation and increasing drought risk, especially on the European side where the demand is high despite the low supply (Climate Transparency Report, 2020; Water Resources Management Review, 2024). Weaknesses in transparency and the lack of stakeholder involvement, particularly in marginalized constituencies, undermine the institutional trust and restrict the power of collaboration in water-management processes to be required in climate adaptation (Siddiqui and Mirza, 2020; Zeitoun et al., 2011). Strength weaknesses, such as the termination of the functions of Melen Dam due to technical issues, also reduce storage and increase vulnerability of the supply

chains (Water Policy Institute, 2023; Zeshan, 2025). Uncontrolled urban development, industrial discharges, and watershed pollution make these governance failures worse and, as a result, exacerbate the mismatch between equitable access to clean and adequate water resources and fundamental human rights to water and sanitation (Fatima et al., 2021).

Despite the policies of Istanbul appreciating the risks of climate change, their implementation into the adaptive governance systems is still underdeveloped, frequently without the operational mechanisms to deliver flexibility to water allocation and strong monitoring (Climate Transparency Report, 2020; Water Resources Management Review, 2024). According to the literature, integrated water resource management approaches are needed, which should facilitate transparency, institutional capacity, and inclusive decision-making (Pahl-Wostl, 2015; Fatima et al., 2021). Nevertheless, there is a lack of empirical research to investigate the joint effects of institutional reforms, the quality of governance, trust, and transparency to promote climate resilience in the water sector of Istanbul. The gap in this research highlights the pressing necessity of the targeted research that would guarantee the sustainable water security, social justice, and equitable distribution of resources as mega-cities such as Istanbul experience an increasing climate stress and an increasing vulnerability of infrastructure.

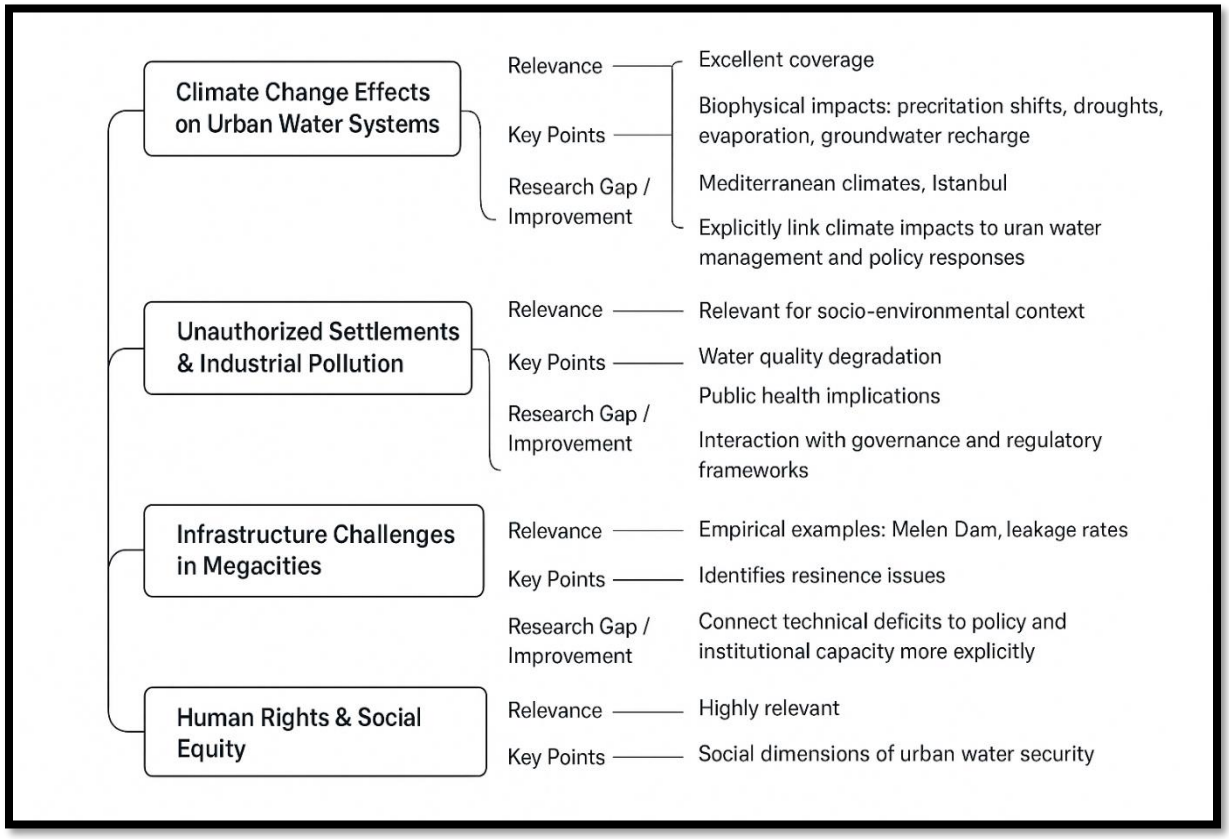

Table 1: Assessment of Literature on Urban Water Systems: Themes, Relevance, and Research Gaps

Section	Relevant Assessment
Climate Change Effects on Urban Water Systems	Excellent coverage of biophysical impacts on precipitation shifts, droughts, evaporation, groundwater recharge. References to Mediterranean climates and Istanbul are highly relevant. Minor improvement: explicitly link these effects to urban water management and policy responses.
Unauthorized Settlements & Industrial Pollution	Relevant for socio-environmental context. Addresses water quality and public health implications. Could benefit from highlighting **how these issues interact with governance and regulatory frameworks,** since that is a key research gap.
Infrastructure Challenges in Megacities	Strong relevance. Provides empirical examples (Melen Dam, leakage rates) and identifies resilience issues. Could be strengthened by connecting **technical deficits to policy and institutional capacity** more explicitly
Human Rights & Social Equity	Highly relevant. Integrates social dimensions of urban water security. Needs emphasis on how this links to governance and climate adaptation policies.
Governance & Institutional Capacity	Crucial for a comprehensive review. Highlights fragmentation, transparency, stakeholder participation, and adaptation gaps. Could further tie in examples of how governance

3. Research Objectives

This study aims to comprehensively analyze the challenges confronting Istanbul's water security in the context of climate change, urban expansion, and infrastructural constraints. The specific objectives are as follows:

- To examine the impacts of climate change on Istanbul's water availability and quality, with a particular focus on vulnerabilities exacerbated by rapid urban growth and limitations in existing water infrastructure.
- To assess socio-economic disparities in access to safe and sufficient water, exploring the associated human rights challenges faced by marginalized and underserved communities within the city.
- To evaluate the effectiveness of current governance frameworks and institutional responses in addressing water security concerns and facilitating climate adaptation strategies.
- To develop integrated, practical recommendations aimed at advancing sustainable water management, enhancing infrastructure resilience, and promoting rights-based, equitable governance in Istanbul's urban water sector.

Research Questions

To guide the investigation, this study seeks to answer the following key research questions:

- How do climate change impacts, in conjunction with rapid urbanization and existing infrastructure weaknesses, influence the overall water security landscape in Istanbul?
- What are the spatial and social patterns of inequitable access to safe and adequate water supply in Istanbul, and what are the principal human rights concerns arising from these disparities?

- To what extent do current governance structures and institutional mechanisms effectively support equitable and climate-resilient water management, and where do critical gaps and deficiencies exist?

4. Methodology

The paper under analysis follows a qualitative approach to document analysis in order to conduct a detailed study of water security issues in Istanbul. The study will gain a comprehensive understanding of water infrastructure vulnerabilities in the city through the analysis of a large body of policy documents, climate change research and technical evaluation. Empirical data on water supply, demand, quality, and infrastructure is available in official reports by the municipal and environmental authorities in Istanbul. Such reports allow cross-checking the results and situate the water management in Istanbul in the framework of global climate change and increasing urban pressures. The methodology offers a clear and descriptive perspective of the contemporary water security issues, including physical and institutional determinants of the city resilience.

A synthesizing analytical framework was developed to integrate the dimensions of water security in Istanbul that can be critical. Climatic variables such as precipitation and drought frequency and temperature dynamics were reflected into the evaluation of infrastructural resilience, in terms of the functioning status of dams and pipelines. The governance was evaluated in terms of transparency, involvement of decision-making cycles, and accountability systems in the management of water. The human-rights vision was combined with a strong one, as it is important to note that the access to water is to be provided to everyone who has to live on the same territory, with the special focus on the marginalized groups. It was a holistic system that made possible the discovering of complex interdependencies between natural water availability, infrastructural capacity, quality of governance as well as the social-equity issue. It therefore provides a multi-layered knowledge that will be important to address the issue of water security facing the growing climatic effects and urbanization.

An integrated conceptual framework was created to combine the water security dimensions in Istanbul, which is considered vital. The variables were climatic variables (precipitation, drought frequency, and temperature dynamics) included in the measurement of the resilience of infrastructural elements (specifically, the working condition of dams and pipelines). The governance was also assessed in terms of transparency, inclusion in the decision-making cycles and accountability systems in water management. A strong approach was paired with the human-rights approach to specify that access to water should be provided to all the occupants of the land with special focus on the disadvantaged groups. This holistic approach allowed unveiling the multicomponent interdependency of natural water availability, infrastructural capacity, good governance, and social-equity issues. It, therefore, provides a multi-layered body of knowledge that will be invaluable in tackling water security issues that will emerge as a result of increased climatic effects and urbanization.

5. Results

5.1 Climate Change Impacts on Water Availability and Quality

The hydrological variability imposed by the climate changes, including the change in the precipitation pattern and the growing frequency of droughts, has become the increasing threat to the water supply of Istanbul. According to the Turkish State Meteorological Service (2024) and the Istanbul Water and Sewerage Administration (ISKI, 2023), there is a decline in the annual rainfall in the range of 10 -15 percent in comparison to the historical averages, an outcome further enhanced by prolonged dry seasons and a lower rate of groundwater recharge. The storage has declined considerably in surface reservoirs, and the Melen Dam is running at less than capacity

since 2021 due to technical issues and climate strains, hence less storage of over 500 million cubic meters (ISKI, 2024). Increased temperature increases the evaporation losses, which aggravate water shortage. Ecosystems are also harmed by episodic flooding and higher loads of pollutants in the ecosystem, thus worsening the quality of water (UNEP, 2022). This convergence of climatic variations and infrastructural shortages brings a big challenge to the provision of reliable and clean water to the increasing population of Istanbul.

5.2 Urban Growth and Infrastructure Vulnerabilities

The high rate of urbanization in Istanbul has posed high strains on water infrastructure which has left it vulnerable. About 65 percent of the city population is located on the European side, which means that it covers only 35 percent of the water resources of the entire city, which creates a spatial discrepancy between demand and supply (ISKI, 2023). Illegal settlements along major watersheds increase the dangers of pollution due to untreated sewage and contaminants (Erdogan et al., 2021). Older infrastructure, in particular, the operational issues of Melen Dam and widespread pipeline leaks which cause 3040 percent non-revenue water, prevents efficient delivery of water, as well as making the systems vulnerable (Fatima et al., 2021). These vulnerabilities continue to increase without investments in modernization and continuous maintenance which jeopardize the future water security and equitable access.

5.3 Socio-Economic Inequities and Human Rights Challenges

Major socio-economic differences define access to safe and adequate water in Istanbul, and this violates the established human-right practices. Even though piped water is supplied to more than 90 per cent of the city residents, residents of informal settlements face irregular supply and access to contaminated sources, and the access level is lower than 75 per cent in marginalized neighborhoods (Kaya & Yilmaz, 2022; Freedom from Hunger, 2021). The inequities are a contributor of greater rates of waterborne disease and compromised economic opportunities of the vulnerable populations leading to failure of social cohesion. The inability of ensuring fair water access violates the United Nations-confirmed right to water and sanitation (UNGA, 2010) exemplifying the institutional shortcomings in the provision of the marginalized communities in the backdrop of the demands of climate change and urbanization.

5.4 Governance, Transparency, and Institutional Coordination

The Water management of Istanbul is characterized by fragmentation, lack of transparency and inclusion of stakeholders. ISKI and several municipal governments have similar mandates and a poor coordination system, which hinders holistic water management (Transparency International Turkey, 2024). There is also a lack of data integration and marginalized communities are not often involved in the decision-making process undermining the transparency and accountability. Financial and managerial inefficiency restrain active infrastructure maintenance and climate-changing adaptation and thus lower the institutional responsiveness. The lack of cohesion in governance and the inability to act together and deliver fair governance limits the development of resiliency and inclusive water systems.

5.5 Environmental Degradation and Pollution Risks

The progressive pollution by informally-treated waste discharged by informal settlements and adjacent industrial areas is being observed in critical watersheds (Erdogan et al., 2021; Kaya and Yilmaz, 2022). The consequent increase in nutrient loads, pathogenic load, heavy-metal concentration, and the hydrocarbon contaminations significantly worsen the quality of the water, thus making a significant risk to the health of people and the environment. Adherence to regulation

on pollution control is still intermittent based on institutional weaknesses and limited monitoring capacities. The synergetic effect on the changes in land-use combined with poor enforcement of the regulatory regimes and the continual degradation of the water sources puts farther stress on the vulnerability of Istanbul water sources and makes it very important to consider integrative environmental protection within the context of water-resource management.

5.6 Integrative Water Security Framework and Indicator Analysis

A multi-dimensional analytical framework has also been applied in assessing water availability, infrastructure flexibility, governance transparency, accountability, and inclusiveness in a series of key documents. Indicator's indications indicate lack of consistency in the areas of infrastructure maintenance and community engagement processes. Although some policies will recognize climate resilience, there is very little operational translation to these ideas. It is also true that transparency and inclusion of the stakeholders on a regular basis has been witnessed but still it is partial or not present which exposes substantive weaknesses in governance. These results outline long-term underinvestment, disjointed control, and socio-economic inequalities as overlapping issues that deteriorate the water security in Istanbul in the backdrop of increasing climate and urbanization-driven challenges.

5.7 Emerging Themes and Contradictions

According to the emerging narrative, it is always possible to trace the impact of climate change on water, inadequacies in infrastructure, and sharp socio-economic inequality. However, there is still some apparent incongruity between the inspirational language of policy and the practical capabilities of the institutional organizations that do the implementation. Although there is an official recognition of the necessity in the changes in climate, the current plans often lack operational blueprints or effective mechanisms of accountability. Governance is hindered by failures in coordination that occur between central powers and the sub-national structures undermining the provision of coherent policy execution. Proclamations of human-rights commitments do exist alongside continued inequalities in the allocation of water-service provision to the marginalized populations. Those complexities can help to reveal depth of the issues which are faced during the technical, socio-political and institutional reconciliation in the Istanbul water-security system.

5.8 Institutional Capacity and Policy Implementation Gaps

The discussion suggests that the lack of the adequate institutional capacity and a strong problem in the implementation of policies are the critical barriers to the proper water management. Although water management structures exist on a large scale, the lack of human and financial resources, especially in such agencies as ISKI and local governments, is also a major obstacle to the infrastructure condition and timely change of management approaches. Diffuse authority and the bureaucratic delays also make the decision-making procedure more complicated as it leads to the inconsistent application of the regulatory measures towards the pollution control and illegal urban development. Besides, poor coordination and the policy fragmentation negatively influences the inferences of the climate-adaptation strategies in the overall water governance system. These gaps, which are identified, continue to create systemic weaknesses throughout the water system and thus hinder the way forward to attaining long-term and sustainable water security of the Istanbul population.

6. Discussion

6.1 Interconnections between Climate Stressors, Urbanization Pressures, and Infrastructure Challenges Exacerbating Water Insecurity

A combination of climate change, rapid urbanization and ageing infrastructure contributes to the aggravation of water issues in megalopolis such as Istanbul. Natural water is decreased by less rain and increased droughts and the increased evaporation caused by hotter temperatures causes more strain on the existing high-demand reservoirs. This issue is exacerbated with city growth consuming more water and paving over the ground with concrete so that the water does not enter the soil but instead run over the surface, contaminating it. Simultaneously, poor infrastructure, like the failure of Melen Dam, reduces storage and transportation of water. These issues make a loop where low supply will cause people to use excessive amount of water that will drain resources and worsen the water. It is difficult to adjust because of delays in infrastructure repairs and divided government dominance and hence the weakness of the system. Without collaborating to plan climate changes, urbanization and new infrastructure, water issues will increase making health, employment and equity to be at stake.

6.2 Human Rights Implications of Unequal Water Distribution and Contamination Exposure in Marginalized Communities

Inequal water allocation in urban areas that are developing at a rapid rate really raises numerous human-right concerns, particularly to the disadvantaged and the poor. It is as though, people in such places are left to suffer intermittent coverage, prolonged water inadequacies and even to share dirty water that is close to illegal settlements or industrial dumping sites. It is always that waiting-and-hope state among these communities on clean water, which is completely unjust when you consider the right to basic amenities of all people. It basically puts a spanner in the entire concept where everybody should receive secure, dependable water, which according to the international law is a fundamental human right. Purchasing bottled or other substitute water is a tremendous financial blow that continues to leave many people in the poverty rut leaving them out of the good employment opportunities or other means of uplifting their lives. To top it all, the existence of prolonged periods of poor water elevates a billion health hazards, which expose people to water-related diseases. The fact that the escalation of this issue in the informal settlements indicates that the system is neglecting these areas due to the prejudices of the society- virtually a massive governance failure. Going about making water policies fairer would entail the fact that we earnestly have to put the social justice into the equation, would target the people who are the most affected by it, place services where they are the most affected, and that we actually see the standards we devise achieved. Maintaining water as a human right is critical in case we are interested in cities developing sustainably and remaining together during climate change.

6.3 Institutional and Governance Challenges Including Fragmented Oversight, Limited Stakeholder Participation, and Enforcement Gaps

Urban water governance has the challenge of the endemic institutional fragmentation. It manifests itself in conflicting mandates between agencies, role ambiguity, and inadequate coordination among the municipal authorities, environmental regulators, and water utilities. Such fragmentation brings about inefficiencies, redundancy and ineffective accountability that slows down decision making and diminishes capacity to respond to crises. Also, there are few opportunities to engage stakeholders, in any substantive way, particularly representatives of marginalized and informal groups. This compromises transparency and the trust of the people on the governance structure. Weak enforcement also undermines the implementation of the policies, where pollution and uncontrolled water extraction is permitted. Lack of real-time information sharing and incomplete

data systems do not allow evidence-based management and responsive planning. When effectively coupled together, these gaps diminish the capacity of the institution to foresee and respond to the shocks caused by climate, protect the vital infrastructure in advance, and reconcile competing demands equitably. To improve governance, it is needed to institutionalize the change to achieve multi-agency coordination, institutions that enforce the process, institutionalize participatory processes and institutionalize the use of technology to create transparent data government.

6.4 Necessity of Integrated Urban Water Management Approaches Incorporating Climate Adaptation and Social Justice

Urban water insecurity is a common issue; therefore, we must have combined water management comprising of hydrology, water infrastructure, and social-political aspects. IUWM is aimed at the coordination of water supply, stormwater, wastewater, and environmental management to optimize the utilization of resources and minimize vulnerability. Most importantly, IUWM implements the principles of climate-adaptation, developing flexible systems of allocation, which adapt to varying hydrology, construct resilient infrastructure, as well as the application of risk-management measures. IUWM is geared towards equal distribution of water, safeguarding vulnerable population and equal power representation. Being a balance between climate and social justice, IUWM prevents increasing inequalities and promotes sustainable livelihood and well-being. Effective IUWM needs to have supporting institutions, multi-sector cooperation, engaged stakeholders and long-term data and capacity building investment. In combination, these solutions will move the cities away the climate-flexible, inclusive water systems that address the rising demands of our fast-growing, climate-vulcanized communities.

6.5 Broader Lessons for Mega-Cities Navigating Similar Climate and Urban Challenges

The challenges faced by Istanbul mirror those confronting many global megacities grappling with rapid urbanization and escalating climate risks. Key lessons highlight the imperative of adopting integrated governance frameworks that overcome institutional fragmentation by fostering coordination across agencies and administrative boundaries. Prioritizing transparency and inclusiveness enhances stakeholder trust and mobilizes diverse capacities necessary for adaptive management. Infrastructure modernization, including investments in climate-resilient and smart water systems, is fundamental to ensuring reliable access in the face of environmental uncertainties. Additionally, addressing socio-economic disparities through targeted policies and human rights-based approaches is critical to avoid deepening vulnerabilities and social inequities. Leveraging emerging technologies such as remote sensing, IoT monitoring, and data platforms can vastly improve decision-making and responsiveness. Ultimately, megacities must embrace holistic urban water management that synergizes climate adaptation with social equity to sustain livable, resilient, and just urban futures worldwide.

Table 2: Systems, Pressures, and Strategic Leverage for Climate-Resilient and Equitable Urban Water Management in Istanbul

System Component	Stress / Pressure	Feedback Loop / Risk Amplification	Strategic Leverage
Water supply & reservoirs	Droughts, reduced precipitation, high urban demand	Over-extraction → reservoir depletion → declining water quality	Expand storage capacity (e.g., Melen Dam project), implement water reuse and efficiency programs, diversify supply sources to buffer climate variability
Urban expansion	Rapid population growth, impervious surfaces, high consumption	Reduced groundwater recharge → increased runoff → water pollution and flood risk	Integrate green infrastructure (e.g., urban wetlands, rain gardens), enforce zoning and land-use planning, incorporate stormwater management in urban design
Social equity	Informal settlements, marginalized communities, unequal access	Vulnerability → exposure to contaminated water → health risks and poverty cycles	Targeted service provision for underserved neighborhoods, subsidized water access, inclusive decision-making processes; for example, improving supply in Istanbul's informal districts like Tuzla and Silivri
Governance & institutions	Fragmented agencies, overlapping mandates, weak enforcement, limited public participation	Delayed crisis response → reduced public trust → ineffective adaptation	Strengthen multi-agency coordination, embed participatory governance, use real-time monitoring and data platforms (e.g., smart water meters and IoT systems in Istanbul), enforce quality standards and compliance

7. Recommendations

The problems in Istanbul are caused by the combination of climate change, accelerated urbanization, and governance limitations. The water security problem in this case needs to be approached in a holistic manner. Urban water management should be sustainable, equitable, and climate-resilient, as per our analysis, which is why we recommend the following.:

7.1 Modernize Water Infrastructure

Invest to upgrade major water infrastructure such as dams, reservoirs and distribution networks to increase storage capacity and reduce leakages. Emphasis is laid on old assets such as the Melen Dam and addressing the non-revenue water wastes which are estimated to be 30-40. To increase resilience in response to climate variability and increment urban demand, modernization must employ modern materials and technology of monitoring. The infrastructure should be sustainable through regular funding and effective project management to provide services that are reliable and enduring to the infrastructure, so that the water supply in Istanbul remains safe despite the changing climatic and population demands.

7.2 Regulate Urban Expansion

Strict land-use planning and enforcement to be used to ensure there is no illegal settlement in the watershed zones. Facilitate sustainable urban growth policies, which also take into account water-resource concerns, to reduce the risk of pollution by untreated sewage and without industrial discharge. Enhance the coordination of the municipal agencies to observe and regulate informal developments. Promote migration or improvement of settlements that have poor sanitation facilities to minimize source of contamination. Conserving watershed integrity will be essential to preserve water quality and ecosystem health and guarantee equitable and safe access to water by all people living in the areas.

7.3 Enhance Pollution Control

There is the need to intensify the implementation of environmental policies regarding domestic sewage and industrial effluents that negatively affect the quality of water in watersheds. There is need to increase surveillance capabilities and impose severe fines to non-compliance. There is a need to encourage investment in wastewater management and provide incentive to cleaner production technologies in the industry. It is essential to incorporate pollution control strategies into the city water governance structures. The elimination of risks of heavy metals, hydrocarbons, and pathogens safeguards the health of the population, reduces the cost of treatment, and promotes sustainable water-resources management.

7.4 Promote Equitable Water Access

Provide policies that ensure continuous availability of safe water to the people in marginalized and informal settlements. Increase the piped water coverage in the areas with low-income to over 75 per cent, hence guaranteeing year-round access. Embrace tariff systems that make it affordable to the vulnerable population. Integrate equity-based goals of water management plans in order to overcome socio-economic inequities. The human right to water will be upheld, and this will improve the social cohesion, the health of the population, and their resilience to water stress caused by climatic changes.

7.5 Improve Governance Coordination

Implement combined governance systems that co-ordinate mandates and decision-making at ISKI, municipality and other stakeholders involved. Increase transparency, accountability and coherence between policies by instituting cohesive information sharing platforms and common planning committees. The marginalized communities should be encouraged to take part in the water governance to encourage inclusive decision making. Empower the institutional capabilities to respond to the climatic and urban pressures in a timely and adaptive manner. Fragmentation is an important issue that should be solved in order to have sound and equitable water management in Istanbul.

7.6 Embed Climate Resilience

The incorporation of climate risk evaluations as part of the design, functioning, and policy of water infrastructure is also a fundamental part of modern water resource management. Adaptive management protocols, which are sensitive to hydrological variability and extreme events, must be formulated. Improvement of early warning measures regarding droughts and floods, as well as the distribution of information promptly to the community and especially to the most vulnerable population is a crucial measure to be used to mitigate it. In addition, the integration of nature-based interventions e.g., watershed restoration and sustainable urban drainage systems is used to mitigate the effects of climatic fluctuations.

7.7 Increase Community Engagement

This research paper suggests that participatory governance structures should be put in place to enable citizens, or in this case, the marginalized communities, to actively participate in the water management decision-making processes. Educational programs on water conservation, prevention of pollution, and climate change adaptation are some of the key elements in this program. Besides this, community-led monitoring and stewardship programmes are supposed to be encouraged in order to create the sense of ownership of the community and in order to encourage sustainability. The proactive involvement of communities is expected to enhance social responsibility, advance the quality of services delivery, as well as create resiliency of both climate and infrastructural related problems.

7.7 Secure Sustainable Financing

Raise a wide fund base, such as public budgets, private investments, grants and international climate finance, to finance water infrastructural developments, pollution mitigation and governance reform. Develop transparent financial management system so that resources are efficiently used and their sustainability ensured. Use investments that will impact equity and climate adaptation to get the maximum social and environmental benefits. To maintain water security in Istanbul, under the increased demand and climate risks, financial sustainability is necessary in the long-term.

8. Conclusion

The water security issues facing Istanbul are as a result of the interaction between climate change, urbanization, and old infrastructure which has created a dangerous situation with high human rights concerns. The climatic changes, including change of precipitations patterns and rising temperatures, have reduced water supplies making drought situations more dangerous, especially in the European section where the water provision is insufficient to support the highly populated urban setting. The lack of structural aspects, such as the inability of the Melen Dam to function, and broad-scale pollution produced by informal settlements, undermine the efficiency of supply and water quality even further. These are some of the stressors that interact and undermine access to safe water in a fair way, which is against internationally recognized human-rights commitments and is a threat to the health and social equity of the affected populations. This situation highlights the dire need of combined practices which include climate adaptation and city planning with the focus on human-based governance.

There is also fragmentation of the governance structure, poor coordination and absence of stakeholder inclusion, and this does not allow adaptive water-management actions. The overlapping authorities, financial limitations, and poor community involvement of various agencies that lack effectiveness in enforcing environmental protection encourage further destruction of the watersheds, reduction of transparency and responsiveness. Lack of participatory governance compounds inequalities especially to the sidelined populations which are subjected to intermittent supply and dangers of contamination. One of the key aspects that should be strengthened is institutional coherence and inclusion should be incorporated into coming up with sound and sustainable urban water systems that address climatic and social needs in Istanbul.

Urban water management in Istanbul requires combined solutions to the water security needs of the city, including the resilient investment of infrastructure, climate risk sensitive planning, inclusive politics, and the protection of human rights. With the focus on equity and social justice, vulnerable communities will not be left behind in solving environmental issues. The Istanbul lessons can be transferred to the wider global issues of urban water crisis in the megacities which

are challenged by climate change and rapid urbanization. The future sustainable solutions will be based on establishing adaptive capacity to conserve water by means of coordination, transparency, community empowerment, and sustainable financing, thus ensuring that the present and future generations have water.

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